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Hydraulics and Pneumatics

For V Semester B.E Mechanical and
VI Semester Mechatronics Students

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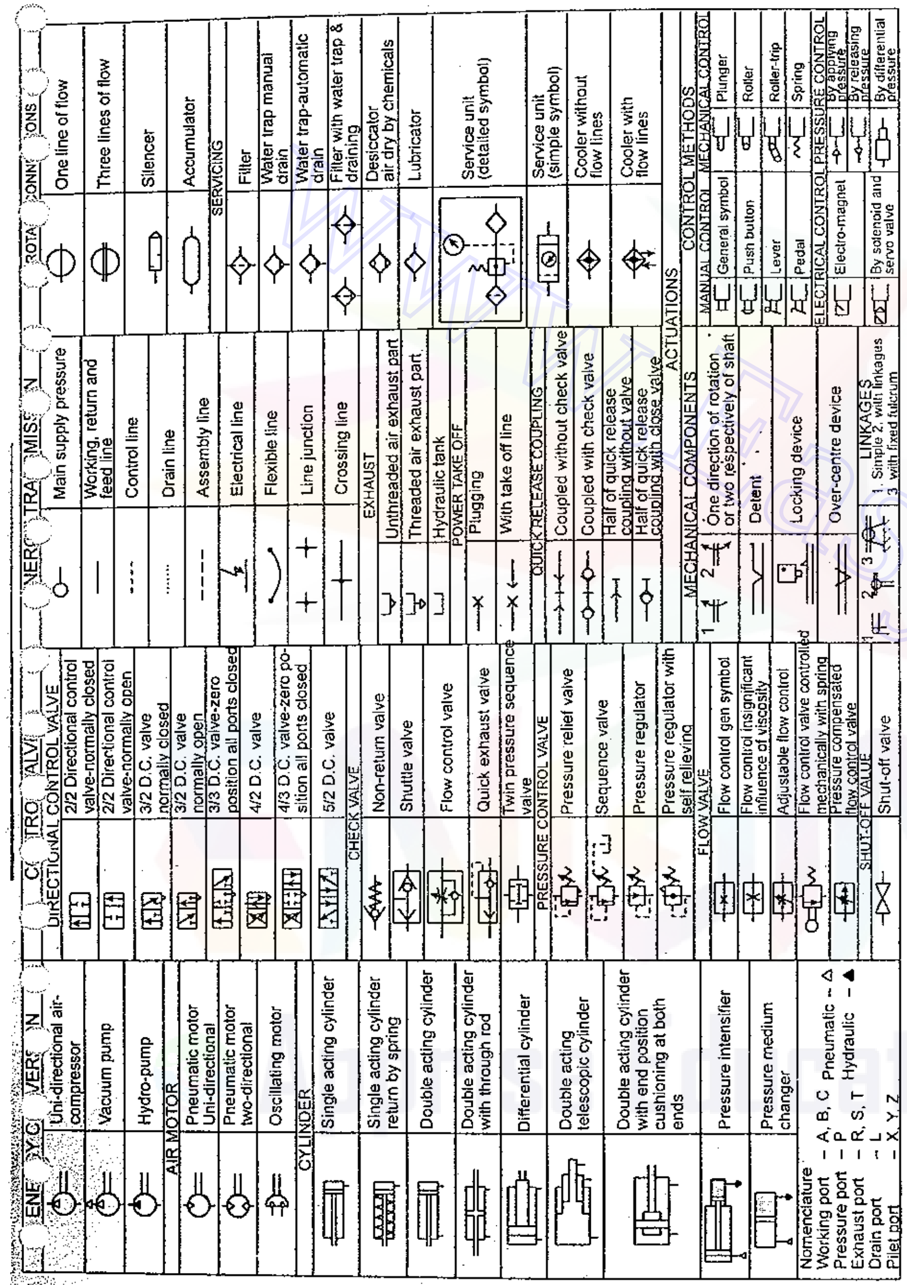

APPLIED HYDRAULICS and PNEUMATICS

APPLIED HYDRAULICS AND PNEUMATICS

For V Semester B.E. Mechanical Students

Strictly As per the Latest Syllabus of ANNA UNIVERSITY

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. Jayakumar

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appa ***Vijayarangan,***
for what I am today.

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PREFACE

> *"Nothing in education is so astonishing as the amount of ignorance it accumulates in the form of inert facts."*
>
> *– **Henry Adams***

*The use of Hydraulics and Pneumatics for power transmission has been increasing spectacularly for the few decades. Today we find applications of fluid power in virtually every branch of industry viz., automobile, machine tool, marine, aviation, agriculture, construction, defense, material handling, transportation, automation, etc. Really, the importance of the subject **"Applied Hydraulics and Pneumatics"** has made me to write a book on it.*

This book is an attempt to provide a compressive introduction to this vast field of fluid power. This book not only outlines the basic principles and terminology of hydraulics and pneumatics systems, it also discusses in detail the construction, operation and application of the many elements used to build up such systems. This book is written in tune with the latest syllabus of Anna University and the syllabus has been taken as a guide for the organisation of this text.

The book is organised into 16 chapters. The diagram on the next page indicates the overall structure of the book. Chapters 1 to 3 are general introduction to the concepts of fluid power which are dealt in detail in later chapters; Chapters 4 to 9 are concerned primarily with the study of technology and applications of Hydraulic systems; and Chapters 10 to 16 are devoted majorly to the study of Pneumatic systems.

The contents are formatted to have 16 chapters, 208 sections, 211 illustrative diagrams, 56 illustrative tables, 54 solved numerical problems, about 236 two mark questions with answers, 40 unsolved problems, etc. Also at the end of each chapter review and summary, key terms one should remember, review questions, and problems for practice are given for the students to consolidate their learning. It is hoped that the approach used in this text will help in demystifying the subject, will embrace the requirements of all the mechanical engineering students, and will earn appreciation of all the fellow teachers.

The author's responsibility here is to stress abundantly that he lays no claim to the original research in preparing this book. Many of the subject matters that are available in the works of eminent authors have been made freely. Perhaps what I may claim, in all modesty, is that I have tried to fashion the vast amount of materials available from primary and secondary sources into coherent body of description and analysis.

Although every care has been taken to make the text free from errors, yet the author shall feel obliged if errors present are brought to his notice. Constructive criticism of the book will be warmly received.

Acknowledgement

A work of this kind would not have been possible to conceive, had it not been for many people they helped directly and indirectly.

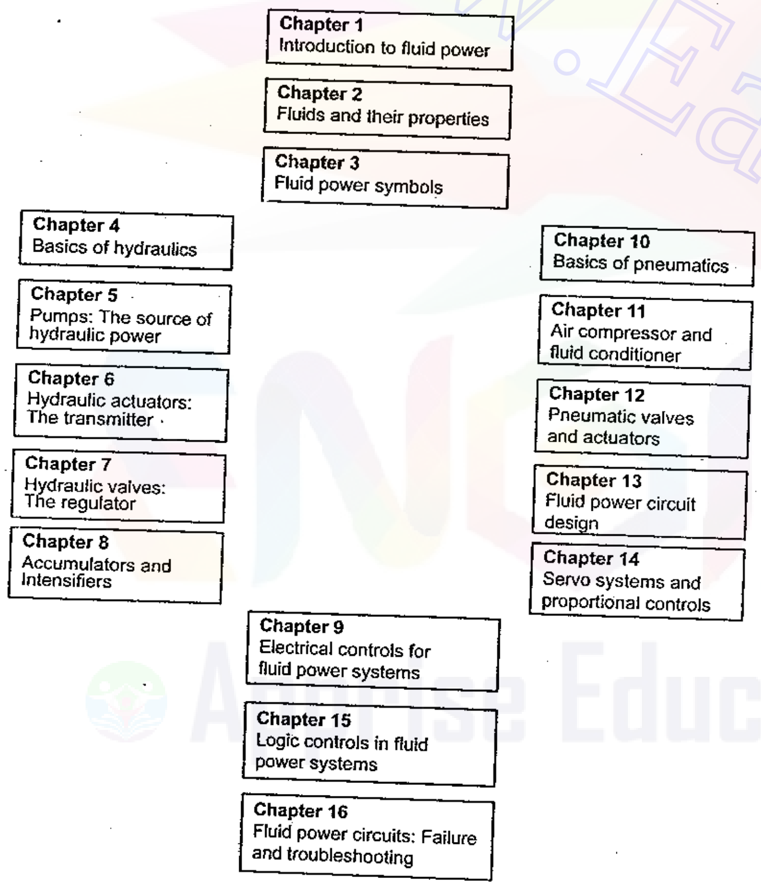
The author will not be pardoned if he does not recognize and acknowledge ***Mr. S. Mohammed*** ***ffi, B.E.,*** *who have contributed immensely to the output of this text, also from whom I learned a* *reat deal while gaining invaluable first-hand experience.*

owe my heartiest thanks to all my colleagues, friends, students, and well wishers for their *ggestions and constant support. I thank sincerely* ***Mr. A. Durai, B.E.,*** *and* ***Lakshmi Publications*** *blishing this book in its present form. Special thanks to* ***Ms. D. Shobana – Himalaya Graphics,*** *ho is responsible for the grand look of this text.*

ally, I would like to make an affectionate acknowledgement to all my family members, *pecially my wife* ***Mrs. Indhu, B.E.,*** *and my little son* ***Snehan,*** *for their forbearance and* *standing.*

ly 2006

V. JAYAKUMAR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Chapter 15
Logic controls in fluid power systems
Chapter 16
Fluid power circuits: Failure and troubleshooting

ANNA UNIVERSITY SYLLABUS

ME 2305 – APPLIED HYDRAULICS AND PNEUMATICS

(Common to Mechanical and Mechatronics Engineering)

2008 Regulation

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1. FLUID POWER SYSTEMS AND FUNDAMENTALS **9 hours**

Introduction to fluid power, Advantages of fluid power, Application of fluid power system. Types of fluid power systems, Properties of hydraulic fluids – General types of fluids – Fluid power symbols.

Basics of Hydraulics – Applications of Pascals Law – Laminar and Turbulent flow – Reynold's number – Darcy's equation – Losses in pipe, valves and fittings.

2. HYDRAULIC SYSTEM & COMPONENTS **9 hours**

Sources of Hydraulic Power: Pumping theory – Pump classification – Gear pump, Vane pump, Piston pump – Construction and working of pumps – Pump performance – Variable displacement pumps.

Fluid Power Actuators: Linear hydraulic actuators – Types of hydraulic cylinders – Single acting, Double acting special cylinders like Tandem, Rodless, Telescopic, Cushioning mechanism, Construction of double acting cylinder, Rotary actuators – Fluid motors, Gear, Vane and Piston motors.

3. DESIGN OF HYDRAULIC CIRCUITS **9 hours**

Construction of Control Components : Director control valve – 3/2 way valve – 4/2 way valve – Shuttle valve – Check valve – Pressure control valve – Pressure reducing valve, Sequence valve, Flow control valve – Fixed and adjustable, electrical control solenoid valves, Relays, Ladder diagram.

Accumulators and Intensifiers : Types of accumulators – Accumulators circuits, sizing of accumulators. Intensifier – Applications of Intensifier – Intensifier circuits.

4. PNEUMATIC SYSTEMS AND COMPONENTS **9 hours**

Pneumatic Components: Properties of air – Compressors – Filter, Regulator, Lubricator Unit – Air control valves, Quick exhaust valves, Pneumatic actuators.

Fluid Power Circuit Design: Speed control circuits, Synchronizing circuit, Pneumo hydraulic circuit, Sequential circuit design for simple applications using Cascade method.

5. DESIGN OF PNEUMATIC CIRCUITS **9 hours**

Servo systems – Hydro-mechanical servo systems, Electro-hydraulic servo systems and Proportional valves.

Fluidics; Introduction to fluidic devices, simple circuits. Introduction to Electro hydraulic Pneumatic logic circuits, Ladder diagrams, PLC applications in fluid power control. Fluid power circuits: failure and troubleshooting.

Total Number of Periods : 45 hours

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Chapter 1 : Introduction to Fluid Power

Chapter 2 : Fluid and Its Properties

Chapter 3 : Fluid Power Symbols

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Chapter 1

Introduction to Fluid Power

> *"Technology, no matter how sophisticated, is useless if it outstrips the abilities of the people to understand, implement, and manage."*
>
> **– William E. Scollard**

> *Educational research indicates we remember 20% of what we READ, 30% of what we HEAR, 40% of what we SEE, 50% of what we SAY, 60% of what we DO, and 90% of what we HEAR, SEE, SAY and DO.*

> *"One machine can do the work of fifty ordinary men. No machine can do the work of one extraordinary man".*
>
> **– Elbert Hubbard**

Learning Objectives

While reading and after studying this chapter, you will be able to:

- ☑ Understand and appreciate the use of fluid power.
- ☑ Differentiate between fluid power systems and fluid transport systems.
- ☑ Identify and compare the basic methods of transmitting power.
- ☑ Recognize and explain the advantages and disadvantages of fluid power.
- ☑ Identify and appreciate the applications of fluid power in various industries/fields.
- ☑ List the basic components required in hydraulic and pneumatic power systems.
- ☑ Describe the basic working principle of hydraulic and pneumatic power systems.
- ☑ Understand the difference between hydraulic, pneumatic, and electromechanical power systems.

CHAPTER 1 INTRODUCTION TO FLUID POWER

1.1. INTRODUCTION

Almost all the development of our present level of technology depends on the evolution of methods for the generation, distribution, and utilisation of power. The energy requirements of the world increases at a faster rate day-after-day. This increasing demand for power requires the continued development of methods for power transmission, control, and utilization. Fluid power technology plays an important role in this task and also it promises to be even more important in the future.

1.1.1. Brief about Fluid Power

The use of fluid power to help human being is probably as old as civilization itself. This is quiet evident from the following historical facts :

(*i*) The water (fluid) was used to generate power through water wheels;

(*ii*) The water (fluid) was transmitted/pumped for irrigation purpose by means of water wheels;

(*iii*) The rivers (fluid) were used as transportation means (to move from one place to another using logs of wood);

(*iv*) The wind (fluid) was used to drive windmills. The windmills were used to grind grains, to pump water, *etc.*;

(*v*) The wind (fluid) was used to propel the ships; and

(*vi*) The wooden valves were used to control water (fluid) flow through bamboo pipes.

Since then, the fluid power technology has been advancing quiet remarkably. The use of fluid power equipment is increasing steadily throughout the world—not only in industrial sectors but also in household applications. Today we find the applications of fluid power in all the fields of engineering viz., mechanical, automobile, agriculture, marine, biomedical, mechatronics, production, aero space, defence, *etc.* Nowadays, the fluid power equipments are used in every walk of industrial life, such as hydraulic elevators, hydraulic presses, hydraulic jacks, hydraulic rams, pneumatic cranes, pneumatic hand tools, air brake system of automobiles and railway coaches, robots, earth-moving equipments, and so on.

In this chapter, we shall present the concept, advantages, drawbacks, applications, and components of a fluid power system.

1.2. FLUID POWER AND FLUID SYSTEMS

1.2.1. What is Fluid Power ?

✓ As we know, *a fluid is a substance which is capable of flowing.* Therefore the fluid can be either a liquid or a gas.

✓ The term 'fluid power' refers to the use of fluids (*i.e.*, liquid and gas) for the development of methods for power transmission, control, and utilization.

✓ ***Definition :*** *Fluid power may be defined as the technology that deals with the generation, control, and transmission of power using pressurized fluids.*

✓ ***Classification :*** In fact, fluid power is the general term. Actually the fluid power systems can be further divided into pneumatic and hydraulic systems, depending on the fluid medium used to transmit force.

In other words,

Fluid Power Systems = Hydraulic Systems + Pneumatic Systems

✓ ***The hydraulic system*** employs liquids (such as water, petroleum oils, and synthetic oils) as the fluid medium.

✓ ***The pneumatic system*** employs gas (most commonly compressed air) as the fluid medium.

1.2.2. Types of Fluid Systems

There are two different types fluid systems. They are :

1. Fluid transport systems, and
2. Fluid power systems.

The differences between them are presented in Table 1.1.

Table 1.1. Fluid transport systems Vs Fluid power systems

1. ***Fluid Transport Systems :*** ✓ The objective of the fluid transport systems is to transport/deliver fluids from one place to another place to achieve some useful purpose.

✓ ***Examples :*** Some of the examples of fluid transport systems include :

(*i*) Transport of water from water reservoirs (such as wells/rivers) to houses/industries using pipe lines; and

(*ii*) Transport of petroleum oil/gas from one country to another through oil/gas pipe lines.

2. ***Fluid Power Systems :*** ✓ The fluid power systems are primarily designed to perform work. That is, these systems use pressurized fluids to produce some useful mechanical movements to accomplish the desired work.

✓ ***Examples :***

(*i*) The oil is used in various construction and earth-moving equipments to accomplish the desired movements and hence to perform the designed work.

(*ii*) The compressed air is used in pneumatic cranes to produce all the required crane movements.

1.3. METHOD OF TRANSMITTING POWER

The three basic methods of transmitting power are :

1. Electrical power transmission,
2. Mechanical power transmission, and
3. Fluid power transmission.
    - (*a*) Hydraulic power transmission, and
    - (*b*) Pneumatic power transmission.

These three methods are explained in Table 1.2. However in practice combination of above methods are used to obtain the most efficient overall system.

Table 1.2. Methods of transmitting power

1. ***Electrical Power Transmission :*** ✓ ***Concept :*** Electrical power is transmitted by imposing an electromagnetic field on a conductor.

✓ ***Suitability :*** They are suitable for power transmission over long distances.

✓ ***Disadvantages :*** The limitations of electric power transmission include magnetic saturation (which may limit the torque developed by an electric motor); material limitations (which may affect the speed); and heat dissipation problem.

2. ***Mechanical Power Transmission :*** ✓ ***Concept :*** Mechanical power is transmitted by employing a variety of kinematic mechanisms such as belts, chains, pulleys, sprockets, gear trains, bar linkages, and cams.

✓ ***Suitability :*** They are suitable for the transmission of motion and force over relatively short distances.

✓ ***Disadvantages :*** The disadvantages of mechanical power transmission include lubrication problems, limited speed and torque control capabilities, uneven force distribution, and relatively large space requirements.

3. *Fluid Power Transmission :*

(a) Hydraulic Power Transmission : ✓ *Concept :* Hydraulic power is transmitted by the pressure and flow of liquids. The most common liquids used are petroleum oils.

✓ *Suitability :* They are suitable for power transmission over intermediate distances. That is, they can be employed over greater distances than mechanical types but not as far as electrical systems.

✓ *Advantages :* Hydraulic systems are mechanically stiff, and can be designed to give fast operation and move very heavy loads.

✓ *Disadvantages :* The disadvantages of hydraulic system include hydraulic fluid leakage; impairment of system operation by contamination; and fire hazards with flammable hydraulic fluids.

(b) Pneumatic Power Transmission : ✓ *Concept :* Pneumatic power is transmitted by the pressure and flow of compressed gases. The most commonly used gas is air.

✓ *Suitability :* They are suitable for power transmission over intermediate distances.

✓ *Advantages :* Pneumatic systems use simple equipment, have small transmission lines, and do not present a fire hazard.

✓ *Disadvantages :* The disadvantages of pneumatic system include a high fluid compressibility and a small power-to-size ratio of components.

1.4. ADVANTAGES OF FLUID POWER

It is reckoned that the future industries' will depend largely upon automation to increase productivity. The activities associated with automation include remote and direct control of production operations, manufacturing processes, and materials handling. In this regard, the *fluid power is considered as the muscle of automation* because it offers many advantages as shown in Table 1.3.

Table 1.3. Advantages of fluid power system

1. *Ease and accuracy of control :* With the use of simple levels and/or push buttons, the fluid power system can facilitate easy starting, stopping, speeding up or slowing down, and positioning forces that provide any desired power.[††]

[††] *Do You Know ? :* Using a fluid power system, one can achieve very high power with tolerances as precise as one ten-thousandth of an inch. That's why it is being used in aircrafts by an aircraft pilot to raise or lower his landing gear.

2. *Multiplication of force :* The fluid power system can multiply forces (in the order of 10^2 to 10^5 times) easily and efficiently.

3. *Constant force or torque :* The fluid power system is the only system which can provide constant force or torque irrespective of variations in speed, whether the work output moves a few millimeters per minute, several metres per minute, or thousands of revolutions per minute.

4. *Simplicity, safety, economy :* When compared to electrical and mechanical systems, generally the fluid power system uses fewer moving parts. That's why they are simpler to maintain and operate. As a result, it also maximizes safety, compactness, and reliability.

5. *Other benefits :* Some of the other advantages of using the fluid power systems include :

(i) High power-to-weight ratio.
(ii) Instant reversal of motion with accuracy is possible.
(iii) Automatic protection against overloads.
(iv) Infinitely variable control (of output force, output torque, and output speed).
(v) Requires lesser space.
(vi) Relatively smooth and quiet operation.
(vii) Greater efficiency (about 85–90%) and economy due to low friction losses.
(viii) Low inertia and ease of shock absorption (during actuator motion, reversal, start, and stop).

1.4.1. Advantages of Hydraulic Power Systems

Table 1.3 lists the general advantages which are applicable to both hydraulic and pneumatic power systems. However the specific advantages of using hydraulic power systems are presented in Table 1.4.

Table 1.4. Advantages of hydraulic power systems

1. Hydraulic power is easy to generate, transmit, store, regulate and control, maintain and transform.

2. Hydraulic power systems can generate and transmit large tonnes and forces to any part of a machine. It is also possible to amplify (*i.e.*, multiply) the force and power.

3. The hydraulic power systems provide reversible, infinitely variable speed and load control.

4. They can achieve accurate feed back control of load, position, *etc.*
5. They offer cushioning for shock loads. Hence the noise and vibration produced are minimal.
6. The wear of the system is reduced due to the self-lubrication action of the transmission medium.
7. They are mechanically safe, compact and can be easily controlled.
8. The power-to-weight ratio of a hydraulic power system is comparatively higher than that for electrical and mechanical power systems.
9. The hydraulic output can be linear and rotational. Use of flexible connection hydraulic system permits generation of complex motion, which is impractical with the kinematic linkages such as gear, belts, cams, *etc.*
10. The hydraulic power systems offer safe operation for both operator and machine.
11. Hydraulic elements can be located easily at any place and can be controlled reversely.
12. This system is a better over-load safe power system. This can be easily achieved by using a pressure relief valve.

1 .2. Disadvantages of Hydraulic Power Systems

Table 1.5 presents some of the major disadvantages of hydraulic systems.

Table 1.5. Drawbacks of hydraulic power systems

1. Hydraulic fluid leakage poses many problems to the operations as well as operators.
2. Flammable hydraulic fluids may pose fire hazards thus limiting the upper level of working temperature.
3. Hydraulic elements require special treatments to protect them against rust, corrosion, dirt, *etc.* Otherwise the contaminated elements may impair the system operation.
4. Hydraulic fluids may pose problems if it disintegrates due to ageing and chemical deterioration.

3. Advantages of Pneumatic Power Systems

Table 1.6 presents the specific advantages of using pneumatic power systems.

Table 1.6. Advantages of pneumatic power systems (over hydraulic systems)

1. Since the density of gas (air) is much lower than liquid (oil), the compressed gas (air) can be easily transported/accelerated.
2. Simple construction of pneumatic elements and easier handling.
3. High degree of controllability (of pressure, speed and force of pneumatic medium (air)).
4. Since the viscosity of gas (air) is much lesser than liquid (oil), this results in lesser frictional pressure and power losses.
5. Since pneumatic systems use air, they are cheaper than hydraulic and other systems.
6. The pneumatic systems do not present a fire hazard because of fire-proof characteristics of the medium.
7. Weight of the pneumatic systems are lesser when compared to hydraulic systems.
8. Pneumatic systems have better operational advantages than that of hydraulic systems.
9. Unlike in hydraulic systems, the leakage of pneumatic medium in the pneumatic systems will not affect the operation of the system seriously. Because the pneumatic systems receive the compressed air continuously.

1.4.4. Disadvantages of Pneumatic Power Systems

Table 1.7 presents some of the major disadvantages of pneumatic systems.

Table 1.7. Drawbacks of pneumatic power systems

1. Due to a high fluid (air) compressibility, it is impossible to obtain a precise control of actuator velocities in pneumatic systems.
2. Since pneumatic pressures are quite low due to the compressor design, the pneumatic systems are suitable only for low load and low power applications.
3. The power-to-size ratio of pneumatic components is small.

Note It may be noted that pneumatic power systems should not be considered as competitor for the hydraulic power systems, and vice-versa. Since they are so dissimilar in their characteristics, therefore there are not much problems of selection between them. Usually hydraulic and pneumatic equipment do not compete for the same application. It is also found that a combined circuit (in which oil is used in one part and air in another on the same machine or process) is more efficient than any individual system.

1.5. APPLICATIONS OF FLUID POWER

The applications of hydraulic and pneumatic power systems cannot be simply listed/counted, because new uses of them are being found and adopted every day in all fields. However few of the applications of fluid power are summarised in Table 1.8.

Table 1.8. Applications of fluid power

Sl.No.	Industry/Field	Applications
1.	Manufacturing industry	Hydraulic presses, pneumatic hand tools, hydraulic and pneumatic fixtures, automatic and semi-automatic operating machines such as machines with hydraulic feed, pneumatic drive, automatic indexing machine, hydraulic-driven die-casting machine, hydraulic feed machines, automatic lathe with air-operated equipment, hydraulically operated shaving machines, cutting machines, drilling machines, *etc.*
2.	Automobile industry	Welding equipment using hydraulic controls, hydraulic brakes, automotive transmissions, power steering, power brakes, air conditioning, lubrication, water coolant, and gasoline pumping systems.
3.	Agriculture industry	Hydraulic and pneumatic driven elevator conveyors for use in harvesting of grains; fluid power driven farm equipments.
4.	Naval industry	Fluid power used for cargo handling, winches, propeller pitch control, submarine control systems, operation of shipboard aircraft elevators, and drive systems for radar and sonar.
5.	Aviation and Aerospace industry	Hydraulic-actuated landing gears, cargo doors, gun drives, and flight control devices such as rudders, ailerons, and elerons for aircraft; fluid powered missile launching systems.
6.	Mechatronics field	Fluid logic components, servo-controlled pneumatic actuators in robotics and tactile sensing; Fluid power used for operating various mechatronic elements such as spindle drives, feed drives, automatic tool clamping and work clamping, tool magazines and automatic tool chargers, *etc.*
7.	Material handling field	Hydraulic lift truck; hydraulic jacks; hydraulic rams; hydraulic elevators; fluid power driven conveyors; pneumatically operated packing, wrapping and bottling equipments.
8.	Construction field	Fluid power driven earth-moving equipment; fluid power driven brush drive used for cleaning roads, floors, *etc.*
9.	Other industries	Fluid power driven equipment are also widely employed in many other industries such as food processing industries, chemical industries, biomedical industries, pharmaceutical industries, *etc.*

1.6. TYPES OF FLUID POWER SYSTEMS

As discussed in Section 1.2.1, the two main types of fluid power systems are :

1. Hydraulic power system, and
2. Pneumatic power system.

Now we shall discuss the various components and working of hydraulic and pneumatic systems, in the following sections.

1.7. HYDRAULIC POWER SYSTEM

As we know, the hydraulic system uses the pressurized hydraulic liquid as the fluid medium. Also *hydraulic system is always a closed loop system.*

1.7.1. Arrangement

The general arrangement of a basic hydraulic system is shown in Fig.1.1.

1.7.2. Basic Components of a Hydraulic System

A hydraulic system consists of six basic components, as shown in Fig.1.1(*b*). The basic components and their functions are presented in Table 1.9.

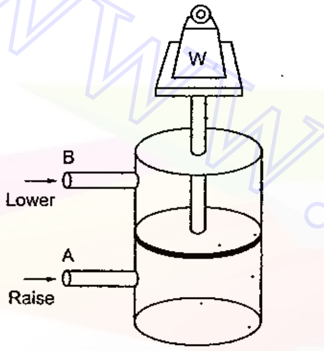
Table 1.9. Basic components[†] of a hydraulic system

1. ***Reservoir (or tank) :*** A reservoir is an oil supply tank. It is provided to hold the hydraulic liquid (usually oil).
2. ***Pump :*** A pump is used to force the liquid into the system.
3. ***Prime mover :*** A prime mover, usually an electric motor, is used to drive the pump.
4. ***Valves :*** Valves are fitted in the system to control liquid direction, pressure, and flow rate.
5. ***Actuator :*** An actuator is provided to convert the liquid energy into mechanical force or torque to do useful work. The actuator is the actual working element of the system. The actuators can be either cylinders (to provide linear motion) or hydro motors (to provide rotary motion).
6. ***Fluid-transfer piping :*** The hydraulic piping is provided to carry the liquid from one place to another.

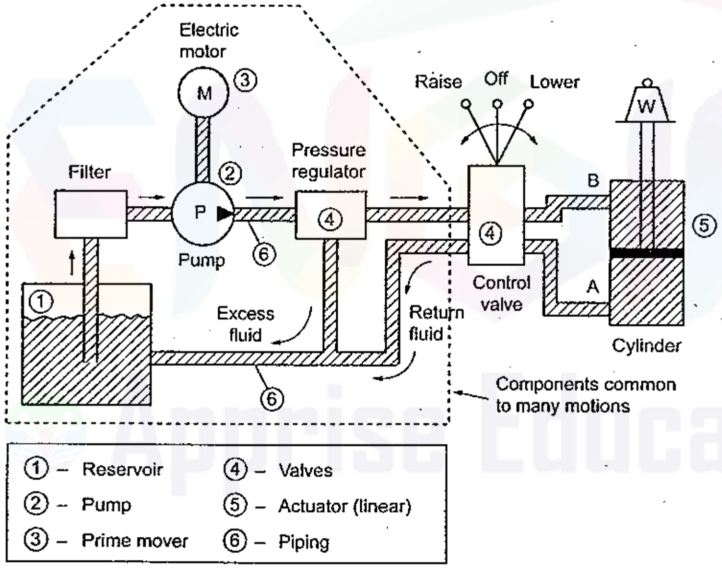
[†] These hydraulic components are studied in detail in subsequent chapters; pumps are discussed in Chapter 5; motors and actuators in Chapter 6; and valves in Chapter 7; and so on.

It may be noted that many different circuit designs are possible for a given application. However, most industrial hydraulic circuits represent some variation in the design of basic components.

The output of the hydraulic system can be determined by the manner in which the various components are arranged.



(a) Hydraulic cylinder



(b) General arrangement of a hydraulic system

Fig. 1.1. Basic hydraulic system with linear hydraulic actuator (cylinder)

1.7.3. Working

1.7.3.1. How does a Hydraulic Cylinder (Actuator) Work ?

The schematic arrangement of the hydraulic cylinder is shown in Fig.1.1(*a*). It consists of a movable piston connected to the output shaft and two parts A and B. If liquid is pumped through port A, then the piston will move up; and if the liquid is pumped through port B, then the piston will move down. Obviously, when the pressurized liquid is pumped at one side of the piston, then the non-pressurized liquid on the other side of the piston must be retrieved back to the liquid tank.

1.7.3.2. Working of the Total Hydraulic System

The total hydraulic system for the task of moving a weight (W) by a distance (D) is shown in Fig.1.1(*b*). The parts enclosed in the dotted-lined box are common to an area of the plant, which may have many linear and rotary hydraulic actuators. In this case, we use only one linear hydraulic actuator.

AC induction motor (M) drives the hydraulic pump (P), so that the fluid is pumped from the tank at the required pressure. The fluid circulated into the system should be clean to reduce the wear of the pump and cylinder; hence a filter is used immediate to the storage tank. Since the pump delivers constant volume of fluid for each revolution of the shaft, the fluid pressure rises indefinitely, until a pipe or pump itself fails. To avoid this, some kind of pressure regulator is used to spill out the excess fluid back to the tank.

Cylinder movement is controlled by a 3-position changeover control valve. One side of the valve is connected to a pressurized fluid line and the fluid retrieval line; and other side of the valve is connected to port A and port B of the cylinder. Since the hydraulic circuit is a closed one, the liquid transferred from the storage tank to one side of the piston, and the fluid at the other side of the piston is retrieved back to the tank.

1.7.3.3. Positions of Valve

Raise : To lift the weight, the pressurized fluid line has to be connected to port A and the retrieval line has to be connected to the port B, by moving the valve position to ‘raise’.

Lower : To bring down the weight, the pressurized fluid line has to be connected to port B and the retrieval fluid line has to be connected to port A, by moving the valve position to ‘lower’.

Off : The weight can be stopped at a particular position (height) by moving the valve position to ‘off’. This disconnects the port A and port B from the pressurized line and the retrieval line, which locks the fluid in the cylinder.

Note Other key points to be noted in the above hydraulic system are :

- ✓ Speed of the cylinder movement can be regulated through the volume flow rate to the cylinder. Precision is very good at low speed.
- ✓ Travel limits are determined by the cylinder stroke.
- ✓ AC induction motor requires a motor starter and overload protection.

1.7.4. An Alternative Hydraulic System

It may be noted that the hydraulic system illustrated in Fig.1.1 uses linear hydraulic actuator (*i.e.*, hydraulic cylinder), which provides linear motion (*i.e.*, up and down movement) of the piston.

An alternative hydraulic system to that in Fig.1.1 is illustrated in Fig.1.2. In this alternative hydraulic system, the linear hydraulic actuator (cylinder) is replaced by a rotary actuator (hydraulic motor). The working of this hydraulic system is exactly the same as that of the system illustrated in Fig.1.2, except that the output motion is rotary motion instead of linear motion.

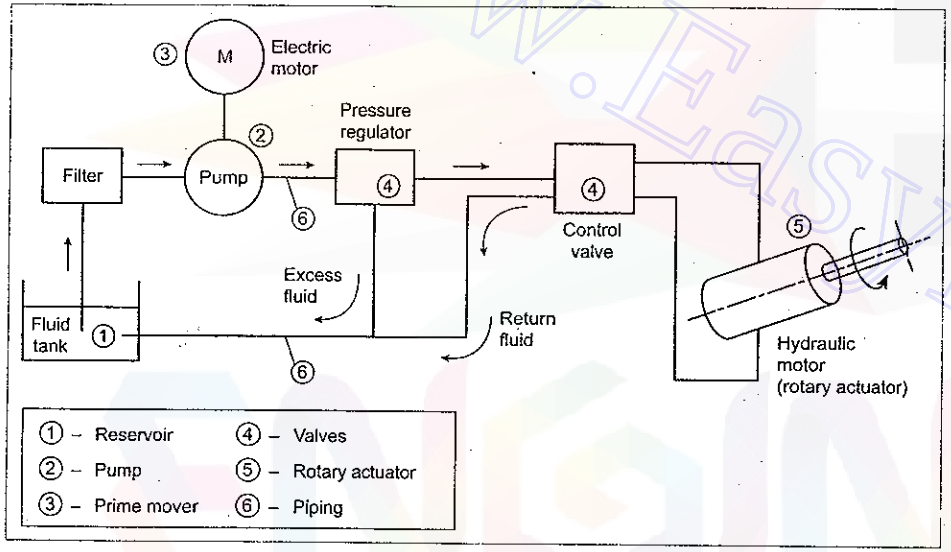


Fig. 1.2. Basic hydraulic system with rotary hydraulic actuator (hydraulic motor)

Note
- ✓ The hydraulic system with linear actuator (Fig.1.1) find applications in various areas. Typical examples are the braking systems used in cars, and the steering gear of aircraft whereby the direction of the rudder and hence the aircraft is controlled.
- ✓ Typical examples using the hydraulic system with rotary actuator (Fig.1.2) are a hydraulic winch drive and the hydrostatic drive on a vehicle.

1.8. PNEUMATIC POWER SYSTEM

We know that the pneumatic system uses mostly the compressed air as its fluid medium. Also, *pneumatic system is always an open loop system.*

1.8.1. Arrangement

The general arrangement of a basic pneumatic system is shown in Fig.1.3.

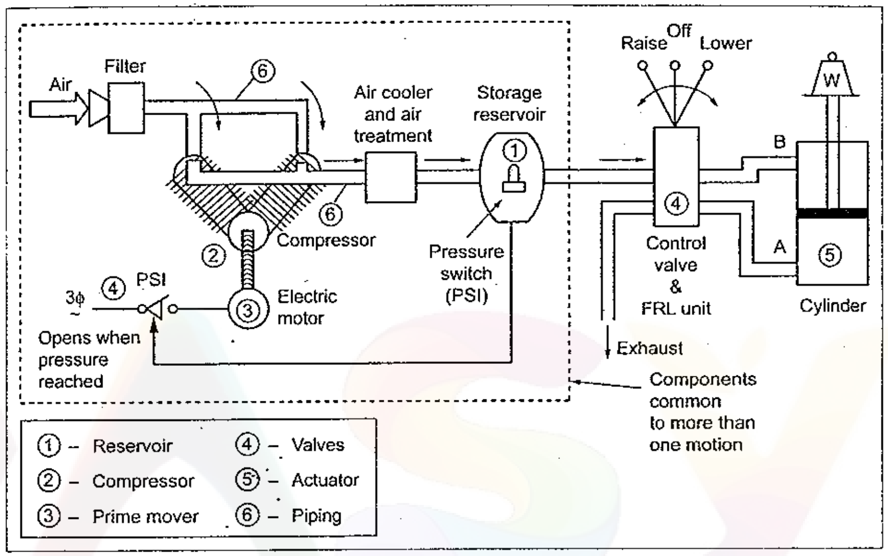


Fig. 1.3. Basic pneumatic system with linear pneumatic actuator (cylinder)

1.8.2. Basic Components of a Pneumatic System

Like hydraulic system, the pneumatic system also have similar six basic components (Fig.1.3). The basic components and their functions are presented in Table 1.10.

Table 1.10. Basic components[†] of a pneumatic system

1.	*Reservoir (or air tank) :* An air tank is provided to store the compressed air required for the operations.
2.	*Compressor :* A compressor is used to compress the incoming atmosphere air so as to increase the pressure of the air.
3.	*Prime mover :* A prime mover, usually an electric motor, is used to drive the compressor.
4.	*Valves :* Valves are fitted in the system to control air direction, pressure, and flow rate.
5.	*Actuator :* An actuator is provided to convert the air energy into mechanical force or torque to do useful work.
6.	*Fluid-transfer piping :* Piping is provided to carry the compressed air from one place to another.

[†] These pneumatic components are studied in detail in subsequent chapters; compressors are discussed in Chapter 11; pneumatic valves and actuators in Chapter 12; and so on.

1.8.3. Working

The total pneumatic system for the task of lifting a weight (W) by a distance (D) is shown in Fig.1.3. The parts enclosed in the dotted-lined box are common to an area of the plant, which may have many linear and rotary actuators. In this case, we use only one linear hydraulic actuator.

Air is drawn from the atmosphere through the air filter and raised to the required pressure by an air compressor. Air contains significant amount of water vapour and also the air temperature is raised considerably by the compressor. So the air must be cooled before using it in the system, which results in condensation.

The compressed air is stored in the reservoir, which has a water outlet at the bottom of the reservoir and a pressure switch (PSI) to control the pressure of the compressed air (by controlling the motor). Pressure switch stops the motor when the required pressure is attained and starts the motor when the pressure falls down the mark.

The outlet of the reservoir is connected to a component called F.R.L. (Filter – Regulator – Lubricator) unit, which does the following activities :

- ✓ Filters the tiny foreign particles from the compressed air.
- ✓ Regulates the pressure just before entering the system.
- ✓ Lubricates the compressed air for the pneumatic cylinders.

The cylinder movement is controlled by the pneumatic valve. One side of the pneumatic valve is connected to the compressed air line and silencers for the exhaust air and the other side of the valve is connected to port A and port B of the cylinder.

1.8.4. Positions of Valve

Raise : To lift the weight, the compressed air line is connected to port A and the port B is connected to the exhaust air line (silencer B), by moving the valve position to 'raise'.

Lower : To bring down the weight, the compressed air line is connected to port B and the port A is connected to exhaust air line (silencer A), by moving the valve position to 'lower'.

Off : The weight can be stopped at a particular position (height) by moving the valve position to 'off'. This disconnects the port A and port B from the pressurized line and the retrieval line, which locks the air in the cylinder.

Note 1. Few other key points to be noted in the above pneumatic system are :

- ✓ One cannot stop the pneumatic cylinder *precisely* in between the top end position and bottom end position. Most of the industrial applications does not try to stop a pneumatic cylinder in between the ends.
- ✓ Operating pressure in pneumatic systems are generally much lower than those in hydraulic systems. Therefore pneumatic systems require larger actuators than hydraulic systems for the same load.

2. It should be noted that the pneumatic system is an open loop system. That is, the compressed air after being used in driving the actuator is exhausted back into the atmosphere. On the other hand, the hydraulic system is always a closed loop system. That is, the used hydraulic oil is drained back to the reservoir and is repeatedly reused again and again.

1.9. COMPARISON BETWEEN HYDRAULIC, PNEUMATIC AND ELECTRO-MECHANICAL POWER SYSTEMS

Table 1.11 presents the comparison between the hydraulic, pneumatic and electro-mechanical power systems.

Table 1.11. Comparisons of hydraulic, pneumatic, and electro-mechanical power systems

Sl.No.	Description	Hydraulic System	Pneumatic System	Electrical / Electro-mechanical System[†]
1.	Energy	Electrical energy is used to drive the hydraulic pumps, which pressurizes the liquid.	Electrical energy is used to drive the motor of the compressor, which compresses the air/gas.	Electrical energy is used to drive the electric motors.
2.	Medium	Pressurized liquid.	Compressed air/gas.	There is no medium used in this system, rather the energy is transmitted through the mechanical components.
3.	Energy storage	Accumulator (limited).	Reservoir (good).	Batteries (limited).
4.	Regulators	Hydraulic valves.	Pneumatic valves.	Variable frequency drives.
5.	Transmitters	Transmitted through hydraulic cylinders, and hydraulic rotary actuators.	Transmitted through pneumatic cylinders, pneumatic rotary drives, and pneumatic rotary actuators.	Transmitted through the mechanical components like gears, cams, screw-jack, *etc.*
6.	Distribution system	Limited, basically a local facility. Upto 100 m, flow rate (v) $= 2 - 6$ m/s.	Good, can be treated as a plant wide service. Upto 1000 m, flow rate (v) $= 20 - 40$ m/s.	Excellent, with minimal loss.
7.	Operating speed	$V = 0.5$ m/s.	$V = 1.5$ m/s.	

[†] Electro-mechanical system is nothing but transmitting the mechanical power by employing a variety of kinematic mechanisms such as belts, chains, pulleys, sprockets, gear trains, bar linkages, and cams, with the use of electrical power as a primary source.

Sl.No.	Description	Hydraulic System	Pneumatic System	Electrical / Electro-mechanical System†
8.	Positioning accuracy	Precision upto ± µm can be achieved depending on expenditure.	Without load change, precision of 1/10 mm is possible.	Precision to ± µm and easier to achieve.
9.	Stability	High, since oil is almost incompressible and pressure level is considerably high.	Low, since air is compressible.	Very good values can be achieved using mechanical links.
10.	Forces	Protected against overload, with high system pressure of upto 600 bar, very large forces can be generated. F < 3999 kN.	Protected against overload. Forces are limited by pneumatic pressure and cylinder diameter. F < 30 kN at 6 bar.	Not over-loadable. Poor efficiency due to downstream mechanical elements. Very high forces can be realized.
11.	Energy cost	Medium.	Highest.	Lowest.
12.	Linear actuators	Hydraulic cylinders. It can produce very high force.	Pneumatic cylinders. It can produce medium force.	Short motion via solenoid, otherwise via mechanical conversion.
13.	Rotary actuators	Hydraulic rotary drives and hydraulic rotary actuators. – Low speed – High turning moment – Good control – Motion can be stalled	Pneumatic rotary drives and pneumatic rotary actuators. – Wide speed range – Accurate speed – Difficult to control	AC and DC motors – Simple and powerful. AC motors – Cheap DC motors – better control.
14.	Controllable force	Controllable, high force.	Controllable, medium force.	Possible with solenoid and DC motors. Needs cooling, hence complicated.
15.	Work environment	Dangerous, unsightly and fire hazardous because of leakage.	Noisy.	Danger, because of electric shock.

REVIEW AND SUMMARY

✓ *In this chapter, the concept, advantages, drawbacks, applications, and components of the fluid power system are presented.*

✓ ***Fluid power** may be defined as the technology that deals with the generation, control, and transmission of power using pressurized fluids.*

✓ *The term 'fluid power' is the general term used for hydraulics and pneumatics. The **hydraulic system** employs liquids (such as water, petroleum oils, and synthetic oils) as the fluid medium. The **pneumatic system** employs gas (most commonly compressed air) as the fluid medium.*

✓ *There are two different types of fluid systems : 1. Fluid transport, and 2. Fluid power. The objective of the **fluid transport system** is to transport/deliver fluids from one place to another place to achieve some useful purpose.*

✓ ***The fluid power systems** use pressurized fluids to produce some useful mechanical movements to accomplish the desired work.*

✓ *The three basic methods of transmitting power are :*

1. *Electrical power transmission – Suitable for long distances.*
2. *Mechanical power transmission – Suitable for over relatively short distances.*
3. *Fluid power transmission – Suitable for over intermediate distances.*

✓ *The fluid power is considered as the muscle of automation because it offers many advantages such as : 1. Ease, and accuracy of control; 2. Multiplication of force; 3. Constant force or torque; and 4. Simplicity, safety, economy.*

✓ *The various advantages and disadvantages of both hydraulic and pneumatic systems are also presented separately in this chapter.*

✓ *The applications of fluid power are found in almost all fields. The various fields of application of fluid power include manufacturing industry, automobile industry, agriculture, naval industry, aviation and aerospace industry, mechatronics field, and material handling field.*

✓ *The two main types of **fluid power systems** are :*

1. Hydraulic power system, and 2. Pneumatic power system.

✓ ***Basic components of a hydraulic system** are :*

1. *Reservoir (or tank),*
2. *Pump,*
3. *Prime mover,*
4. *Valves,*
5. *Actuator, and*
6. *Fluid-transfer piping.*

✓ ***Basic components of a pneumatic system are :***

1. *Reservoir (or air tank),*
2. *Compressor,*
3. *Prime mover,*
4. *Valves,*
5. *Actuator, and*
6. *Fluid-transfer piping.*

✓ *The working of basic hydraulic and pneumatic systems are explained with the illustration for the task of moving a weight by a height.*

✓ *At the end of the chapter, the hydraulic, pneumatic, and electro-mechanical power systems are compared and contrasted.*

KEY TERMS ONE SHOULD REMEMBER

Fluid
Fluid power
Fluid system
  Fluid transport system
  Fluid power system
Power transmission methods
  Electrical power transmission
  Mechanical power transmission
  Fluid power transmission

Hydraulic power system
Pneumatic power system
Reservoir
Pump
Prime mover
Valve
Actuator
  Hydraulic cylinder
  Hydraulic motor

Fluid-transfer piping
Pressure regulator
Filter
Control valve
FRL unit
Compressor
Pressure switch

REVIEW QUESTIONS

hort Answer Type Questions

1. Define the term 'fluid power'.
2. Distinguish between fluid transport and fluid power systems.
3. Name three basic methods of transmitting power.
4. Under what situations, electrical, mechanical, and fluid power transmissions are suitable ?
5. "Fluid power transmission systems can be employed over greater distances than mechanical types but not as far as electrical system". – Explain.
6. What is the fundamental difference between hydraulic and pneumatics ?
7. List any four advantages of using the fluid power.
8. Why is fluid power considered as the muscle of automation ?
9. In comparison with hydraulic systems, why are pneumatic systems suitable only for low load and low power applications ?

10. List any five applications of fluid power in the manufacturing industry.
11. List any five applications of hydraulic power.
12. List any five applications of pneumatic power.
13. What are the two main types of fluid power systems ?
14. What are the basic components that are required for a hydraulic system ?
15. List the basic components of a pneumatic system.
16. What is the purpose of an actuator ?
17. Mention the purpose of the following components in any fluid power system :
    (*a*) Prime mover, and (*b*) Valves.
18. What is the function of a reservoir ?

Essay Answer Type Questions

1. Compare and contrast between the various basic methods of transmitting power.
2. List and explain any five major advantages of using the fluid power.
3. (*a*) Bring out the advantages and disadvantages of using a hydraulic power system.
   (*b*) List out the advantages and disadvantages of using a pneumatic power system.
4. List out the applications of fluid power employed in different industries/fields.
5. (*a*) What are the basic components that are required for a hydraulic system ? Also mention their functions.
   (*b*) With a neat hydraulic circuit, explain the working of a basic hydraulic system with linear actuator for the task of moving a weight by a distance.
6. (*a*) List the basic components of a pneumatic system and also give their functions.
   (*b*) With a neat pneumatic circuit, explain the working of any one pneumatic application.
7. Compare and contrast between hydraulic, pneumatic, and electro-mechanical power systems.

□□

Chapter 2

Fluids and its Properties

"The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency."
– Bill Gates

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them."
– Sir William Biagg

"Give me a lever long enough and a fulcrum on which to place it, and I shall move the world."
– Archimedes

Learning Objectives

While reading and after studying this chapter, you will be able to:

- ☑ Appreciate the primary functions of a fluid in any fluid power system.
- ☑ Define and classify the fluid.
- ☑ Understand the difference between a liquid and a gas.
- ☑ Identify and appreciate the various properties desired of a medium in a fluid power system.
- ☑ Explore the significance of each properties of fluids.
- ☑ Examine the types of fluid available for hydraulic systems.
- ☑ Select a better hydraulic fluid for a given application.

CHAPTER 2

FLUIDS AND THEIR PROPERTIES

2.1. INTRODUCTION

The fluid is an essential and important component of any fluid power system. No other component of the system must perform as many functions or meet as many requirements as the fluid. The fluid must not only provide a medium for efficient power transmission, but it must also lubricate, cool, protect from corrosion, not leak excessively, and perform numerous other functions depending on the system design. There is no single fluid which can be employed for all applications. The selection of a fluid for a particular fluid power application has become a complicated and very challenging task. Thus it is necessary for the fluid power designer to have at least an elementary understanding of the terminology prevalent in the specification of fluids.

In this chapter, we shall examine the different types of fluids, and present the various properties which are important in the selection and use of fluids.

2.1.1. Functions of a Fluid in a Fluid Power System

The various functions/purposes of the fluid in a fluid power system can be summarised as shown in Table 2.1.

Table 2.1. Functions of a fluid in any fluid power system

1. To transmit power (basic purpose).
2. To lubricate moving parts.
3. To seal gaps and clearances between mating components.
4. To dissipate heat generated by internal friction.
5. To prevent rust and corrosion.
6. To remove unwanted and harmful impurities from the system.

2.2. FLUIDS

2.2.1. What is a Fluid ?

A fluid may be defined as follows :

"A fluid is a substance which is capable of flowing."

or

"A fluid is a substance which deforms continuously when subjected to external shearing force, thereby capable of flowing."

2.2.2. Characteristics of a Fluid

Basic characteristics of a fluid are :

1. It has no definite shape of its own, but conforms to the shape of the containing vessel.
2. Even a small amount of shear force exerted on a fluid will cause it to undergo a deformation which continues as long as the force is applied continuously.

2.2.3. Classification of Fluids

Fluids can be classified into :

1. Liquids, 2. Gases, and 3. Vapours.

2.2.4. Liquids

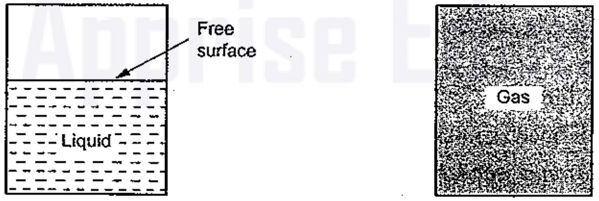
2.2.4.1. What is a Liquid ?

Liquid is a fluid which possesses a definite volume for a given mass independent of the shape of its container. In simple terms, *liquid possess definite mass and volume but no definite shape.*

2.2.4.2. Characteristics of a Liquid

A liquid exhibits the following characteristics :

1. A liquid is difficult to compress. Hence for many purposes it is regarded as incompressible.
2. A given mass of liquid occupies a fixed volume, irrespective of the size and shape of its container.
3. Since the liquid is assumed to be incompressible, it will form a free surface if the volume of the container is greater than that of the liquid, as shown in Fig.2.1(*a*).
4. In liquids, the spacing between the molecules is relatively large when compared to solids, which means that inter-molecular cohesive forces are smaller in liquids. This allows the liquid molecules to move freely within the liquid mass.
5. All known liquids vapourise at narrow pressures above zero, depending on the temperature.



(a) Free surface of a liquid

(b) Gas always occupies the complete container volume

Fig. 2.1. Behaviour of a fluid in a container

2.2.5. Gases

2.2.5.1. What is a Gas ?

Gas is a fluid which has definite mass, but no definite volume and shape.

2.2.5.2. Characteristics of a gas

A gas exhibits the following characteristics :

1. A gas is comparatively easy to compress and hence it is regarded as a compressible fluid.
2. A given mass of a gas has no fixed volume and will expand continuously unless restrained by a containing vessel.
3. It will completely fill any vessel in which it is placed. Therefore it does not form a free surface, as shown in Fig.2.1(*b*).
4. In gas, the spacing between the molecules is extremely large when compared to solids and liquids, which mean that intermolecular cohesive forces are extremely small in gases. So the molecules of gases have greater freedom of movement. That's why they fill the container completely in which they are placed.
5. The volume of the gas is dependent on its temperature and pressure. For instance, if the volume of the gas decreases then the pressure and temperature of it increases.

2.2.6. Comparison Between Liquid and Gas

Table 2.2 summarises the various characteristics of the liquid and gas.

Table 2.2. Liquid Vs Gas

Sl.No.	Liquid	Gas
1	Possess a definite volume for a given mass, but conforms to the shape of the container.	Has a definite mass, but does not possess a definite volume and conforms to the shape of the container.
2	Since it possess a definite volume, it forms a free surface if the volume of the container is greater than the volume of the liquid filled.	Since it does not possess the definite volume, it expands and occupies the whole volume of the container.
3	Incompressible fluid.	Compressible fluid.
4	Spacing between the molecules is relatively large when compared to solids, but relatively very less when compared to gas.	Spacing between the molecules is extremely large when compared to solids and liquids.
5	Can be contained in open vessel.	Always need to be contained in a closed vessel.

2.2.7. Vapour

2.2.7.1. What is a Vapour ?

Vapour is a gas whose temperature and pressure are such that it is very near the liquid state. (Example : Steam).

Note Fluids can also be classified as ideal fluids and real fluids. Also based on the Newton's law of viscosity, fluids are also categorised into : (*i*) Newtonian fluids; (*ii*) Non-Newtonian fluids; (*iii*) Plastic fluids; and (*iv*) Ideal fluids.

2.3. PHYSICAL PROPERTIES OF FLUIDS

The following properties of fluids are of general importance to the study of fluid power systems.

2.4. DENSITY

The density of a fluid is that quantity of matter contained in unit volume of the substance. The density can be expressed in three different ways as discussed below.

2.4.1. Mass Density

✓ ***Definition :*** Mass density (ρ), also known as ***specific mass*** or simply ***'density'***, is defined as the mass of the fluid per unit volume.

✓ ***Formula :***

$$\boxed{\text{Mass density} = \frac{\text{Mass}}{\text{Volume}}} \qquad \ldots (2.1)$$

✓ ***Units :*** kilograms per cubic metre (kg/m³)

✓ ***Dimensions :*** ML^{-3}

✓ ***Typical values :*** At atmospheric pressure (*i.e.*, $p = 1.013 \times 10^5$ N/m²) and temperature (*i.e.*, T = 288.15 K), $\rho_{water} = 1000$ kg/m³, and $\rho_{air} = 1.23$ kg/m³.

2.4.2. Weight Density

✓ ***Definition :*** Weight density (w), also known as ***specific weight,*** is defined as the weight per unit volume.

✓ ***Formula :***

$$\boxed{\text{Weight density} = \frac{\text{Weight}}{\text{Volume}}} \qquad \ldots (2.2)$$

✓ ***Relationship between w and ρ :*** Since weight is dependent on gravitational attraction, the specific weight will vary from point to point, according to the local value of gravitational acceleration 'g'. The relationship between w and ρ can be obtained from Newton's second law. That is,

$$\text{Weight/Unit volume} = \frac{\text{Mass}}{\text{Unit volume}} \times g$$

or

$$\boxed{w = \rho g} \qquad \ldots (2.3)$$

✓ ***Units :*** newtons per cubic metre (N/m³).

✓ ***Dimensions :*** $ML^{-2} T^{-2}$

✓ ***Typical values :*** $w_{water} = 9.81 \times 10^3$ N/m³ ; $w_{air} = 12.07$ N/m³

2.4.3. Specific Gravity

✓ ***Definition :*** Specific gravity (S), also known as ***relative density,*** is defined as the ratio of mass (or weight) density of a fluid to mass (or weight) density of a standard fluid.

✓ ***Formula :***

$$\text{Specific gravity} = \frac{\text{Mass (or weight) density of fluid}}{\text{Mass (or weight) density of standard fluid}} \qquad \ldots (2.4)$$

✓ For liquids, the standard mass density chosen is the maximum density of water (which occurs at 4°C at atmospheric pressure). For gases, the standard density may be that of air or hydrogen at a specified temperature and pressure.

$$\boxed{\therefore\ S_{liquid} = \frac{\rho_{liquid}}{\rho_{water}} = \frac{\rho_{liquid}}{998 \text{ kg/m}^3}\ ; \quad S_{gas} = \frac{\rho_{gas}}{\rho_{air}} = \frac{\rho_{gas}}{1.025 \text{ kg/m}^3}}$$

✓ ***Units :*** No units (∵ Relative density is a ratio of two quantities of the same kind, it is a pure number having no units).

✓ ***Dimensions :*** Since it is a pure number, its dimensions are $M^0L^0T^0 = 1$.

✓ ***Typical values :*** $S_{water} = 1.0$; $S_{oil} = 0.9$.

2.4.4. Specific Volume

✓ ***Definition :*** Specific volume (v) is defined as the reciprocal of mass density.

✓ ***Formula :***

$$\boxed{\text{Specific volume} = \frac{1}{\text{Mass density}} = \frac{\text{Volume}}{\text{Mass}}} \qquad \ldots (2.5)$$

✓ ***Units :*** cubic metre per kilograms (m³/kg).

✓ ***Dimensions :*** $M^{-1} L^3$

✓ ***Typical values :*** $v_{water} = 0.001$ m³/kg ; $v_{air} = 0.813$ m³/kg

2.5. VISCOSITY

✓ ***Concept :*** Viscosity is the most important property of the fluid. *Viscosity is the measure of the ability of a fluid to flow.* It is the measure of the fluid's internal resistance to shear or flow at a definite temperature and pressure.

✓ ***Definition :*** Viscosity is defined as the shearing force required to move two plane surfaces relative to one another with a film of fluid between them.

✓ ***Newton's law of viscosity :*** *This law states that the shear stress (τ) on a fluid element layer is directly proportional to the rate of shear strain.* The constant of proportionality is called the coefficient of viscosity.

Mathematically,

$$\boxed{\tau = \mu \cdot \frac{du}{dy}} \qquad \ldots (2.6)$$

✓ Viscosity may be defined/expressed in number of different ways such as :

1. Absolute viscosity, and 2. Kinematic viscosity.

2.5.1. Absolute Viscosity

✓ ***Definition :*** Absolute viscosity (μ), also known as ***coefficient of dynamic viscosity***, is defined as the shear stress (τ) required to produce unit rate of shear strain (du/dy).

✓ ***Formula :*** Rearranging equation (2.6), we get

$$\mu = \tau \Big/ \left(\frac{du}{dy}\right) = \left(\frac{\text{Force}}{\text{Area}}\right) \Big/ \left(\frac{\text{Velocity}}{\text{Distance}}\right) = \frac{\text{Force} \times \text{Time}}{\text{Area}} \text{ or } \frac{\text{Mass}}{\text{Length} \times \text{Time}} \qquad \dots (2.7)$$

✓ ***Units :*** newtons seconds per square metre (N·s/m²) or kilograms per metre per second (kg/m/s). [But it should be noted that the coefficient of viscosity is often measured in poise (P); 10 P = 1 kg/m/s.]

✓ ***Dimensions :*** $ML^{-1}T^{-1}$

✓ ***Typical values :*** $\mu_{water} = 1.14 \times 10^{-3}$ kg/m/s (or 0.0114 P); $\mu_{air} = 1.78 \times 10^{-5}$ kg/m/s.

2.5.2. Kinematic Viscosity

✓ ***Definition :*** Kinematic viscosity (ν) is defined as the ratio of dynamic viscosity to mass density.

✓ ***Formula :***

$$\boxed{\text{Kinematic viscosity, } \nu = \frac{\text{Dynamic viscosity}}{\text{Mass density}} = \frac{\mu}{\rho}} \qquad \dots (2.8)$$

✓ ***Units :*** square metres per second (m²/s). [But it should be noted that kinematic viscosity is often measured in strokes (St); 10^4 St = 1 m²/s.]

✓ ***Dimensions :*** L^2T^{-1}

✓ ***Typical values :*** $\nu_{water} = 1.14 \times 10^{-6}$ m²/s (or 0.0114 St); $\nu_{air} = 1.46 \times 10^{-5}$ m²/s.

Note 1. The instrument most oftenly used by engineers and technicians to measure the viscosity of liquids (oils) is the ***Saybolt viscometer*** or ***viscosimeter.*** Interested readers can refer Article 1, Appendix I, to understand how to determine viscosity using the Saybolt viscometer.

2. The measured viscosity is usually expressed as Seconds Saybolt Universal (SSU) or Saybold Universal Seconds (SUS), at certain temperature. The majority of hydraulic systems operate most efficiently with fluids having the viscosity ranges : 135 to 165 SSU; 185 to 230 SSU; and 275 to 315 SSU.

3. The empirical relationship between the viscosity in SUS and cS can be given as below :

$$\boxed{\begin{aligned} \nu(\text{cS}) &= 0.226\,t - \frac{195}{t}, \quad t \le 100 \text{ SUS} \\ \nu(\text{cS}) &= 0.220\,t - \frac{135}{t}, \quad t > 100 \text{ SUS} \end{aligned}}$$

where
ν = Kinematic viscosity in cS, and
t = Time measured in SUS or in simply seconds.

4. ***SAE viscosity grade :*** The commercial classification of oils established by the Society of Automotive Engineers (SAE) relates viscosity range to a SAE number. For example, SAE 20 oil has a viscosity of 120 to 185 SSU/SUS at 130°F and SAE 30 oil has a viscosity of 185 to 225 SSU/SUS at the same temperature.

2.5.3. Significance of Viscosity

Various components within a system may have different requirements such as low or high viscosity.

1. If the fluid is too thick (*i.e.,* viscosity is higher than the recommended), then the following behaviours will result in the system :
   - ✓ Increases in load and hence increased power loss.
   - ✓ High operating temperatures because there will be internal friction.
   - ✓ Excessive wear of parts.
   - ✓ Reduces internal leakage.
2. If the fluid is too thin (*i.e.,* viscosity is lesser than the recommended), then the following behaviours will happen in the system :
   - ✓ Less internal friction.
   - ✓ Smaller pressure losses in pipes and valves.
   - ✓ Increase in control action and component response.
   - ✓ Increases internal and external leakage.
   - ✓ Cannot lubricate properly.
   - ✓ Lead to unnecessary rapid wear of moving parts.

Thus a compromise in viscosity requirements must be made.

2.5.4. Effect of Temperature and Pressure on Viscosity of Liquids

Effect of temperature : Temperature has an adverse effect on the viscosity of the hydraulic oils. ***The viscosity of the liquids decreases with increase in temperature.*** This is because of the shear stress in the liquids (due to the intermolecular cohesion) decreases with increase of temperature.

Effect of pressure : The viscosity of the liquids is not appreciably affected by the changes in pressure. However, high pressures will affect the viscosity of the liquids. During high pressures, the energy required for the relative movement of the molecules is increased. Therefore, ***the viscosity of liquids increases with increasing pressure.***

2.5.5. Effect of Temperature and Pressure on Viscosity of Gases

Effect of temperature : If the temperature of a gas increases, the molecular interchange will increase. Therefore ***the viscosity of a gas increases with increase in temperature.***

Effect of pressure : Over the normal ranges of pressures, the viscosity of a gas is found to be independent of pressure. But it is affected by very high pressures.

2.5.6. Viscosity Index

✓ ***Definition :*** The viscosity index (V.I) of a liquid is a number indicating the effect of a change in temperature on viscosity. The V.I is expressed in some arbitrary numerical values.

✓ ***Concept :*** The viscosity of high V.I oils is less sensitive than the viscosity of low V.I oils. In other words, the rate of change in viscosity with changes in temperature is relatively less with high V.I oils than with low V.I oils.

✓ ***Formula :*** The V.I of any hydraulic fluid can be calculated by the following equation :

$$\boxed{\text{V.I} = \left(\frac{L-U}{L-H}\right) \times 100} \qquad \dots (2.9)$$

where
L = Viscosity in SUS of 0–VI oil at 100°F,
U = Viscosity in SUS of unknown–VI oil at 100°F, and
H = Viscosity in SUS of 100–VI oil at 100°F.

2.6. COHESION AND ADHESION

✓ ***Cohesion :*** Cohesion means intermolecular attraction between molecules of the same liquid. It enables a liquid to resist small amount of tensile stresses. Cohesion is an tendency of the liquid to remain as one assemblage of particles.

✓ ***Adhesion :*** Adhesion means the attraction between the molecules of a liquid and the molecules of a solid boundary surface in contact with the liquid. This property enables the liquid to stick to another body.

2.7. SURFACE TENSION

✓ A liquid, being unable to expand freely, will form an interface with a second liquid or gas. Molecules deep within the liquid repel each other because of their close packing. Molecules at the surface are less dense and attract each other. When half of their neighbours are missing, the mechanical effect is that the surface is in tension. This phenomenon is known as surface tension.

✓ The effect of surface tension is to reduce the surface of a free body of liquid to a minimum. Surface tension effects can be reduced by the addition of detergents.

2.8. CAPILLARITY

✓ Capillarity is a phenomenon by which a liquid (depending upon its specific gravity) rises into a thin glass tube above or below its general level.

✓ This phenomenon is due to the combined effect of cohesion and adhesion of liquid particles.

✓ Capillarity action is a serious source of error in reading liquid levels in fine-gauge tubes. To minimise errors due to capillarity, gauge glasses having a larger diameter may be used to read the level of liquids.

2.9. VAPOUR PRESSURE

✓ The pressure exerted by a vapour which is in equilibrium with the liquid is known as vapour pressure.

✓ The vapour pressure will increase with the increase in temperature.

✓ Boiling of liquids will occur when the vapour pressure is equal to the pressure above the liquid. By reducing the pressure, boiling can be made to occur at temperatures well below the boiling point at atmospheric pressure. For example, if the pressure is reduced to 0.2 bar (0.2 atm), water will boil at a temperature of 60°C.

2.10. CAVITATION

✓ When the liquid pressure is dropped below the vapour pressure due to a flow phenomenon, then there will be local boiling and a cloud of vapour bubbles will form. This phenomenon is known as cavitation.

✓ Cavitation causes serious damage in almost any component in a hydraulic system. Cavitation can affect the performance of hydraulic machinery such as pumps, turbines, and propellers.

2.11. COMPRESSIBILITY

✓ All fluids are compressible to some extent. Compressibility of a liquid causes the liquid to act much like a stiff spring.

✓ The ***coefficient of compressibility*** is the fractional change in a unit volume of liquid per unit change of pressure. Mathematically,

$$\text{Compressibility,} \quad \boxed{C = \frac{(\Delta V/V)}{\Delta P}} \qquad \dots (2.10)$$

where
ΔV = Change in volume,
V = Original volume, and
ΔP = Change in pressure.

✓ Generally it is desirable to have the hydraulic fluid which has the minimum compressibility. That is, the fluid with minimum compressibility will be more stiffer.

2.12. BULK MODULUS

✓ Bulk modulus is the reciprocal of compressibility.

- ✓ It is the measure of compressibility of a fluid. Mathematically,

$$\boxed{\text{Bulk modulus, } K = \frac{-1}{\text{Compressibility}} = \frac{-\Delta P}{\left(\frac{\Delta V}{V}\right)}} \qquad \ldots (2.11)$$

- ✓ The higher the bulk modulus, the less elastic or more stiffer the liquid. Usually high bulk modulus values are desirable since they result in more stable and less elastic systems.

OTHER IMPORTANT PROPERTIES OF HYDRAULIC FLUIDS

2.13. CLOUD POINT

- ✓ ***Definition :*** Cloud point is defined as the temperature at which wax or other dissolved solids begin to crystallise and become noticeable when liquids are chilled under specified conditions.
- ✓ ***Significance :*** The cloud point is of interest for use at low temperatures. Many liquids have no cloud point.

2.14. POUR POINT

- ✓ ***Definition :*** The temperature at which an oil will congeal[†] is known as the pour point. In other words, the pour point of an oil indicates the temperature below which the oil will not flow freely.
- ✓ ***Significance :*** This property is very important for hydraulic systems required to operate in extremely cold weather.
- ✓ Chemical additives can be used to lower the pour point.
- ✓ Any fluid used for hydraulic purposes should have a pour point well below its minimum operating temperature.

2.15. FLASH AND FIRE POINTS

- ✓ ***Flash point :*** The flash point is the minimum temperature at which sufficient liquid is vapourized under specified conditions to create a mixture that will burn if ignited. As the name 'flash' indicates, burning at this point is only an instantaneous flash.
- ✓ A high flash point is desirable because it indicates good resistance to combustion and a low degree of evaporation at normal or working temperatures.
- ✓ ***Fire point :*** The fire point is the minimum temperature at which sufficient vapour is continuously generated to sustain combustion.

[†] Congeal = (Cause to) become semi-solid by cooling.

- ✓ ***Significance of flash and fire points :*** Flash and fire points indicate the temperature at which the liquid begins to volatilize. A lower flash or fire point is an indication that the liquid has become contaminated with a more volatile product (such as a fuel).
- ✓ ***Autogenous ignition temperature (AIT) :*** It is the temperature at which ignition occurs spontaneously.

2.16. DEMULSIBILITY

- ✓ ***Definition :*** The property of hydraulic fluid to separate rapidly and completely from moisture and to resist emulsification is known as demulsibility.
- ✓ ***Significance :*** This property is considerably significant because the operation of many hydraulic systems are conductive to the forming of moisture or of stable water-in-oil emulsions.
- ✓ Highly refined, hydraulic oils have excellent demulsibility characteristics. Also it is found that used or contaminated liquids are more likely to emulsify with water than new liquids.

2.17. OXIDATION STABILITY

- ✓ ***Definition :*** Oxidation stability is defined as the ability of a liquid to resist reaction with oxygen or oxygen-containing compounds.
- ✓ ***Significance :*** This is an important property that affects storage life of hydraulic fluids and performance life of hydraulic fluids used in open systems.

Note In addition to the property of oxidation stability, other noteworthy important chemical properties include :

(a) ***Chemical stability :*** It refers to the ability of hydraulic fluids to be chemically stable under the imposed conditions.
(b) ***Thermal stability :*** It refers to the ability of hydraulic fluids to resist decomposition by temperature only.
(c) ***Hydraulic stability :*** It refers to the ability of hydraulic fluids to resist reaction with water.

2.18. FILM STRENGTH, OILINESS AND LUBRICITY

- ✓ The three properties film strength, oiliness and lubricity are pertained to lubricating characteristics of liquids. These properties can be improved with the use of additives.
- ✓ ***Film strength :*** Film strength is the ability of a surface film to resist rupture by the penetration of asperities during sliding or rolling. Generally the higher viscous fluids have higher film strengths.
- ✓ ***Oiliness :*** Oiliness is the property of a liquid which causes films of two liquids of identical viscosity to exhibit different coefficients of friction.
- ✓ ***Lubricity :*** Lubricity is the ability of a liquid to impart low friction under boundary conditions.

2.19. COMPATIBILITY

- ✓ ***Definition :*** Compatibility is the ability of the hydraulic fluid to be compatible with the system.
- ✓ That is, the hydraulic fluid should be compatible with the materials used in the hydraulic system, including metals, plastics, surface coatings, elastomers, lubricants, and other hydraulic fluids. If the hydraulic fluid in any way attacks, destroys, dissolves, or changes any part of the hydraulic system, the system may become inoperable. Similarly, any changes in the hydraulic fluid caused by interaction with the system materials can also cause system malfunction. Therefore, any hydraulic fluid must be compatible with the systems.

2.20. VOLATILITY

- ✓ The volatility of a liquid describes the degree and rate at which it will vapourize under given conditions of temperature and pressure.
- ✓ It is desirable that a hydraulic fluid have low volatility.

2.21. CORROSIVENESS

- ✓ The corrosiveness of a hydraulic fluid refers to its tendency to promote or encourage corrosion in a hydraulic system.
- ✓ Obviously, it is desirable to maintain the corrosiveness of a hydraulic fluid at as low level as possible. For this purpose, rust- and corrosion-preventive synthetic chemicals are usually added with hydraulic fluids.

2.22. NEUTRALIZATION NUMBER

- ✓ The term 'Neutralization number' is used to express an acidity or alkalinity of lubricating liquids and hydraulic fluids.
- ✓ ***Definition :*** The neutralization number is defined as the number of milligrams of potassium hydroxide required to neutralize all the acids present in one gram of the sample.

2.23. REQUIRED QUALITIES OF A GOOD HYDRAULIC FLUID

Any good hydraulic fluid should possess the majority of the properties listed in Table 2.3.

Table 2.3. Required properties of a good hydraulic fluid

1.	Stable viscosity characteristics.
2.	Good lubricity.
3.	Compatibility with system materials.
4.	Stable physical and chemical properties.
5.	Good heat dissipation capability.
6.	High bulk modulus and degree of incompressibility.
7.	Adequate low-temperature properties (such as cloud point, pour point and freezing point).
8.	Good flammability characteristics (such as flash and fire points).
9.	Low volatility.
10.	Good demulsibility.
11.	Better fire resistance.
12.	Lower foaming[†] tendency.
13.	Nontoxicity.
14.	Good oxidation stability.
15.	Better rust-and corrosion-preventive qualities.
16.	Low density and specific gravity.
17.	Low coefficient of expansion.
18.	Simple and easy handling.
19.	Ready availability.
20.	Inexpensive.

Since it is impossible for any single hydraulic fluid to provide all these desirable characteristics, therefore the fluid power designer should compromise in some properties so as to select the fluid which provides the overall requirements for a particular application.

[†] ***Difference between an emulsion and a foam : An emulsion*** is defined as an intimate dispersion of one liquid within another. It is a mixture of two liquids and not a solution with one liquid dissolved in the other. ***A foam*** is an emulsion in which the dispersed phase is a gas rather than a liquid.

2.24. TYPES OF HYDRAULIC FLUIDS

Nowadays a wide range of hydraulic fluids are used in industries. Because of the wide and vastly different areas of application, the hydraulic fluids have been classified by many different systems based on their different characteristics such as physical properties, chemical types, operating capabilities, utility, or specific applications.

However, one of the most widely used classification of hydraulic fluid is based on a separation into two general classes :

1. Petroleum base hydraulic oils, and
2. Non-petroleum base hydraulic oils.
   - (*a*) Water,
   - (*b*) Emulsions,
   - (*c*) Glycols,
   - (*d*) Water glycols,
   - (*e*) Phosphate esters,
   - (*f*) Silicate esters,
   - (*g*) Castor oils, etc.

Now we shall discuss the above hydraulic fluids, briefly, in the following sections.

2.24.1. Petroleum Oils

2.24.1.1. Description

- ✓ Petroleum base hydraulic fluids were among the first liquids employed as hydraulic or power transmission fluids.
- ✓ The typical petroleum oils include : Naphthenes, aromatics, paraffins, wax and olefins.
- ✓ Paraffinic oils have higher viscosity index compared to naphthenic oils, that's why they are more suitable for the hydraulic systems where the oil temperature varies greatly.

2.24.1.2. Advantages of Petroleum Oils

- ✓ Good lubricating characteristics.
- ✓ Protection against rust, corrosion, sludge, and foam formation.
- ✓ Longer life.
- ✓ Better heat dissipating capability.
- ✓ Better sealing property.
- ✓ Generally these oils have a high viscosity index (approximately 100) so that they may be used over a wide temperature range.

2.24.1.3. Disadvantages of Petroleum Oils

- ✓ Low fire resistance.
- ✓ Tendency to oxidize rapidly.

2.24.2. Water

2.24.2.1. Description

- ✓ Most probably water is the least expensive hydraulic fluid available. Water is treated with chemicals before being used in a fluid power system. This treatment removes undesirable contaminants. Water is also passed through a strainer to remove any solid particles.

2.24.2.2. Advantages of Water

- ✓ Inexpensive.
- ✓ Available in abundance.
- ✓ Ideal fire resistance fluid.
- ✓ Viscosity of water is very low and does not change much with increase in temperature. (For instance, the kinematic viscosity of water is 1.5 cSt (*i.e.*, centistroke) at 40°F and 0.3 cSt at 200°F.)

2.24.2.3. Disadvantages of Water

- ✓ Does not possess lubricating property.
- ✓ Evaporates soon and hence it can be used only over a limited range of temperature.
- ✓ Highly corrosive in nature.

Note Since the demerits of water outweighs its merits, nowadays water is very rarely used as a hydraulic fluid.

2.24.3. Emulsions

2.24.3.1. Description

- ✓ *Emulsions are water-oil mixtures.*
- ✓ The emulsions are available in two general types : Oil-in-water emulsions or water-in-oil emulsions.
- ✓ The oil-in-water emulsion has water as the continuous base and the oil is present in lesser amounts as the dispersed media. In the water-in-oil emulsion, the oil is in continuous phase and the water is the dispersed media.

2.24.3.2. Advantages of Emulsions

- ✓ Acceptable corrosion and lubricating properties.
- ✓ Emulsion stability.
- ✓ High viscosity index.
- ✓ Film strength.
- ✓ Good system cooling.
- ✓ Compatibility with most materials.
- ✓ Oxidation stability.
- ✓ Reasonable material cost.

2.24.3.3. Disadvantages of Emulsions

- ✓ Depletion of water due to evaporation. It will reduce the viscosity of the fluid and decrease the fire resistance.
- ✓ Demulsification may be a regular problem with water-in-oil emulsions.

2.24.4. Glycols

2.24.4.1. Description

- ✓ The glycols are often referred by several names such as *polyglycols, polyalkylene glycols, and polyethers.*
- ✓ These glycols are extensively used as base stocks and as components for synthetic lubricants and hydraulic fluids, air conditioner lubricants, and heavy duty brake fluids.

2.24.4.2. Advantages of Glycols

- ✓ Good lubricity and antiwear properties.
- ✓ High flash point.
- ✓ High viscosity indices (upto 150).
- ✓ Wide range of viscosities.
- ✓ Low volatility and pour point.
- ✓ Very good solubility characteristics.

2.24.4.3. Disadvantages of Glycols

- ✓ Poor high temperature oxidation properties.
- ✓ Not good fire resistant.

2.24.5. Water Glycols

2.24.5.1. Description

- ✓ Water glycol contains 35 – 60% water, a glycol, and a water-soluble thickener to improve viscosity.
- ✓ Additives are also added to improve anticorrosion, antiwear, and lubricity properties.
- ✓ It is generally considered as fire-resistant.

2.24.5.2. Advantages of Water Glycols

- ✓ Better fire resistance.
- ✓ Comparatively less expensive.
- ✓ Compatible with most pipe compounds and seals.

2.24.5.3. Disadvantages of Water Glycols

- ✓ Fairly low viscosity.
- ✓ Poor corrosion resistance.
- ✓ Not suitable for high pressures or loads.

2.24.6. Phosphate Esters

2.24.6.1. Description

- ✓ Phosphate esters result from the incorporation of phosphorus into organic molecules.
- ✓ Besides as hydraulic fluids, they can also be used as a base stock load, as a part of the base stock, or as an additive.

2.24.6.2. Advantages of Phosphate Esters (over Petroleum Base Fluids)

- ✓ Excellent lubricants.
- ✓ Excellent fire-resistant properties.
- ✓ Good oxidation stability.
- ✓ Good viscosity-temperature characteristics.

2.24.6.3. Disadvantages of Phosphate Esters

- ✓ Fairly expensive.
- ✓ High acidity causes corrosion and accelerates the rate of hydrolysis leading to deposit formation.

Note

1. ***Fire resistant fluids :*** A fire resistant fluid is one that can be ignited but will not support combustion when the ignition source is removed. Some of the fire resistant fluids are water-in-oil emulsions, water glycols, and straight synthetics such as phosphate esters and chlorinated hydrocarbons.
2. The comparison of a few commonly used hydraulic oils is presented in Table 1, Appendix I.
3. In the pneumatic systems, the commonly used fluid is air. The characteristics, advantages, disadvantages will be discussed in detail, in Chapter 10.

SOME ILLUSTRATIVE EXAMPLE PROBLEMS

- ✓ For better understanding of the basic properties of fluid discussed above, some simple numerical problems have been presented below :

On Mass Density, Weight Density, and Specific Gravity

Example 2.1 *A tank truck contains 90,000 litres of a hydraulic fluid having a specific gravity of 0.9. Determine the fluid's weight density, mass density, specific volume, and weight.*

Given data : V = 90,000 litres = $90{,}000 \times 10^{-3}$ m^3 ; Specific gravity = 0.9.

☺ ***Solution : (a) To find weight density (w) :***

We know that,
$$\text{Specific gravity} = \frac{w_{fluid}}{w_{water}}$$

or
$$0.9 = \frac{w_{fluid}}{9810} \qquad [\because w_{water} = 9810 \text{ N/m}^3]$$

or
$$w_{fluid} = \mathbf{8{,}829 \text{ N/m}^3} \quad \textbf{Ans.}$$ ☜

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(b) To find mass density (ρ) :

We know that, $w = \rho g$

or $8{,}829 = \rho \times 9.81$

or $\rho_{fluid} = $ **900 kg/m³ Ans.** ☜

(c) To find specific volume :

We know that, $\text{Specific volume} = \dfrac{1}{\rho} = \dfrac{1}{900} = \mathbf{1.11 \times 10^{-3}\ m^3/kg}$ **Ans.** ☜

(d) To find weight (W) :

We know that, $w = \dfrac{W}{V}$

or $8{,}829 = \dfrac{W}{90{,}000 \times 10^{-3}}$

or $W = $ **794.6 kN Ans.** ☜

On Viscosity

Example 2.2 *A hydraulic fluid has a specific gravity of 1.9 and kinematic viscosity of 6 strokes. What is its dynamic viscosity ?*

Given Data : Specific gravity = 1.9 ; $\nu = 6 \text{ strokes} = 6 \times 10^{-4}\ \text{m}^2/\text{s}$.

☺ ***Solution :*** $\text{Specific gravity} = \dfrac{\rho_{fluid}}{\rho_{water}}$

or $\rho_{fluid} = 1.9 \times 1000 = 1900\ \text{kg/m}^3$

We know that, $\text{Kinematic viscosity } (\nu) = \dfrac{\text{Dynamic viscosity } (\mu)}{\text{Density } (\rho)}$

or $\mu = (6 \times 10^{-4})(1900)$

$= $ **1.14 N-s/m² or 11.4 poise Ans.** ☜

Example 2.3 *The space between two square flat parallel plates is filled with oil. Each side of the plate is 700 mm. The thickness of the film is 15 mm. The upper plate, which moves at 3 m/s requires a force of 125 N to maintain the speed. Determine the absolute viscosity of the oil in units of N-s/m² and cP.*

Given Data : Side = 700 mm or Area of plate $= 0.7 \times 0.7 = 0.49\ \text{m}^2$; $dy = 15$ mm ;

$du = 3$ m/s; $F = 125$ N.

☺ ***Solution :*** $\text{Shear stress, } \tau = \dfrac{\text{Force}}{\text{Area}} = \dfrac{125}{0.49} = 255.1\ \text{N/m}^2$

According to Newton's law of viscosity,

$$\tau = \mu \cdot \frac{du}{dy} \quad \text{or} \quad 255.1 = \mu \left(\frac{3}{15 \times 10^{-3}} \right)$$

or $\mu = $ **1.275 N-s/m² or 1275 cP Ans.** ☜ [∵ 1 N-s/m² = 1000 cP]

Example 2.4 *A hydraulic oil has a viscosity of 210 SUS at 160°F. Find the corresponding viscosity in units of cS and cP. The specific gravity of the oil is 0.9.*

Given Data : $t = 210$ SUS; Specific gravity = 0.9 or $\rho_{oil} = 0.9 \times \rho_{water} = 900\ \text{kg/m}^3$.

☺ ***Solution :*** We know that,

$$\nu(\text{cS}) = 0.220\, t - \frac{135}{t}, \quad \text{for } t > 100 \text{ SUS}$$

$\nu(\text{cS}) = 0.220\,(210) - \dfrac{135}{210} = $ **45.56 cS Ans.** ☜

We also know that, $\mu = \nu \times \rho = (45.56 \times 10^{-6})\ 900$

$= $ **0.041 N-s/m² or 41 cP Ans.** ☜

Example 2.5 *A sample of oil is tested with a 0–VI oil and a 100-VI oil whose viscosity values at 100°F are 500 SUS and 175 SUS respectively. If the viscosity of the sample oil at 100°F is 220 SUS, determine its viscosity of index.*

Given Data : L = 500 SUS; H = 175 SUS ; U = 220 SUS.

☺ ***Solution :*** We know that,

$$\text{V.I} = \frac{L - U}{L - H} \times 100$$

$= \dfrac{500 - 220}{500 - 175} \times 100 = $ **86.15 Ans.** ☜

On Bulk Modulus

Example 2.6 *A 350 cm³ sample of oil is compressed in a cylinder until its pressure is increased from 1 atm to 40 atm. If the bulk modulus equals 1500 MPa, find the change in volume of the oil.*

Given Data : $V = 350\ \text{cm}^3$; $P_1 = 1$ atm = 1 bar ; $P_2 = 40$ atm = 40 bar ;

$\Delta P = P_2 - P_1 = 39\ \text{bar} = 39 \times 10^5\ \text{N/m}^2$; $K = 1500\ \text{MPa} = 1500 \times 10^6\ \text{N/m}^2$.

☺ ***Solution :*** We know that,

$$K = \frac{-\Delta P}{\left(\dfrac{\Delta V}{V} \right)}$$

or
$$\Delta V = -V\left(\frac{\Delta P}{K}\right)$$
$$= -350\left(\frac{39 \times 10^5}{1500 \times 10^6}\right) = -\mathbf{0.91\ cm^3} \quad \textbf{Ans.}$$

$$\therefore \ \% \text{ decrease in volume} = \frac{\Delta V}{V} = \frac{-0.91}{350} \times 100 = 0.26\%.$$

It shows that the oil is highly incompressible.

REVIEW AND SUMMARY

✓ *In this chapter, the different types and the various properties of fluids are examined, which is very important in the selection and use of fluids.*

✓ *The primary functions of a fluid in a fluid power system are :*

1. *To transmit power.*
2. *To lubricate moving part.*
3. *To dissipate heat generated by internal friction.*
4. *To prevent rust and corrosion.*
5. *To remove unwanted and harmful impurities.*

✓ *A fluid is a substance which is capable of flowing.*

✓ *Fluids can be classified into : 1. Liquids, 2 Gases, and 3. Vapour.*

✓ *Liquids are assumed to be incompressible whereas gases are compressible.*

✓ *Liquids possess definite mass and volume but no definite shape.*

✓ *Gas possess definite mass, but no definite volume and shape.*

✓ *The definition, formula, units, and the significance of the following physical properties of fluid are explained in this chapter :*

1. *Mass density,*
2. *Weight density,*
3. *Specific gravity,*
4. *Specific volume,*
5. *Absolute viscosity, and*
6. *Kinematic viscosity.*

✓ *Viscosity is the measure of the fluid's internal resistance to flow.*

✓ *The viscosity of liquid decreases but that of gases increases with increase in temperature.*

✓ ***Viscosity index (V.I)** of a liquid is a number indicating the effect of a change in temperature on viscosity.*

✓ ***Bulk modulus** is a measure of the incompressibility of the fluid. The higher the bulk modulus, the less compressible or stiffer the fluid. Generally it is desirable to have the hydraulic fluid which has the minimum compressibility.*

✓ *The **pour point** of an oil indicates the temperature below which the oil will not flow freely. Any fluid used for hydraulic purposes should have a pour point well below its minimum operating temperature.*

✓ *The **flash point** is the minimum temperature at which sufficient liquid is vapourised under specified conditions to create a mixture that will burn if ignited.*

✓ *The **fire point** is the minimum temperature at which sufficient vapour is continuously generated to sustain combustion. Flash and fire points indicate the temperature at which the liquid begins to volatilize and hence high flash and fire points are desirable.*

✓ *The property of a hydraulic fluid to separate rapidly and completely from moisture and resist emulsification is known as **demulsibility.***

✓ ***Oxidation stability** is defined as the ability of a liquid to resist reaction with oxygen or oxygen-containing compounds.*

✓ ***Lubricity** is the ability of a liquid to impart low friction under boundary conditions.*

✓ ***Compatibility** is the ability of the hydraulic fluid to be compatible with the system.*

✓ *Required properties of a good hydraulic fluid are :*

1. *Stable viscosity characteristics,*
2. *Good lubricity,*
3. *Compatibility with system materials,*
4. *Stable physical and chemical properties,*
5. *Good heat dissipation capability,*
6. *High bulk modulus and degree of incompressibility,*
7. *Adequate low temperature properties,*
8. *Good flammability characteristics,*
9. *Low volatility,*
10. *Good demulsibility,*
11. *Better fire resistance,*
12. *Lower foaming tendency,*
13. *Non-toxicity,*
14. *Good oxidation stability,*

15. *Better rust-and corrosion-preventive qualities,*
16. *Low density and specific gravity,*
17. *Low coefficient of expansion,*
18. *Simple and easy handling,*
19. *Ready availability, and*
20. *Inexpensive.*

✓ *The important types of hydraulic fluids are :*

1. *Petroleum oils,*
2. *Water,*
3. *Emulsions,*
4. *Glycols,*
5. *Water glycols, and*
6. *Phosphate esters.*

✓ *Since water does not possess lubricating property and also it is highly corrosive in nature, therefore the water is rarely used as a hydraulic fluid.*

KEY TERMS ONE SHOULD REMEMBER

Fluids
- **Liquid**
- **Gas**
- **Vapour**

Density
- **Mass density**
- **Specific mass**
- **Weight density**
- **Specific weight**
- **Specific gravity**
- **Relative density**
- **Specific volume**

Viscosity
- **Absolute viscosity**
- **Kinematic viscosity**

Newton's law of viscosity
Coefficient of dynamic viscosity
Saybolt viscometer
Viscosity index
Cohesion
Adhesion
Surface tension
Capillarity
Vapour pressure
Cavitation
Compressibility
Bulk modulus
Cloud point
Pour point
Flash point
Fire point
Demulsibility
Oxidation stability
Chemical stability
Thermal stability
Hydrolytic stability
Film strength
Oiliness
Lubricity
Compatibility
Volatility
Corrosiveness
Neutralization number
Petroleum oils
Emulsions
- **Water-in-oil emulsion**
- **Oil-in-water emulsion**

Glycols
Water glycols
Phosphate esters
Fire-resistant fluids

REVIEW QUESTIONS

Short Answer Type Questions

1. What are the primary functions of a fluid in any fluid power system ?
2. What does the term 'fluid' refer to in fluid power ? How are fluids classified ?
3. Mention any four characteristics of liquids and gases.
4. Differentiate between a liquid and a gas.
5. What is density of a fluid ? What are the three different ways of expressing it ?
6. Define the terms mass density, weight density, and specific gravity.
7. What is meant by 'viscosity' of a fluid ? Also state Newton's law of viscosity.
8. Define the terms absolute viscosity and kinematic viscosity.
9. What is the significance of viscosity, with reference to the selection of hydraulic fluids ?
10. What are the undesirable effects when an oil having very high viscosity is used ?
11. What are the undesirable effects when an oil having very low viscosity is used ?
12. State the effect of temperature and pressure on viscosity of liquids.
13. State the effect of temperature and pressure on viscosity of gases.
14. "The viscosity of liquid decreases but that of gases increases with increase in temperature."—Why ?
15. Define viscosity index ? What do you infer from V.I number of an oil ?
16. What is the difference between cohesion and adhesion ?
17. Define the following terms :
    (*a*) Surface tension, (*b*) Capillarity, (*c*) Vapour pressure, and (*d*) Cavitation.
18. What is meant by the term compressibility of a fluid ? Give the relationship between compressibility and bulk modulus.
19. Why should a hydraulic fluid have high bulk modulus ?
20. Define and state the significance of following properties of a hydraulic fluid :
    (*a*) Cloud point; (*b*) Pour point; (*c*) Flash point; and (*d*) Fire point.
21. What is demulsibility ? Write its significance.
22. What is oxidation stability ? What is the significance of it ?
23. Define the following terms, with reference to hydraulic fluids :
    (*a*) Lubricity, (*b*) Compatibility, and (*c*) Volatility.
24. What is neutralization number of hydraulic fluid ? Write its significance.

25. List few properties of a hydraulic fluid.
26. Name any six hydraulic fluids that are commonly used.
27. Name any three fire resistant fluids ?
28. Why is water not commonly used as a hydraulic fluid ?
29. What are the advantages and disadvantages of petroleum oils as the medium in hydraulic systems ?

Essay Answer Type Questions

1. (*a*) What are the functions of a fluid in any fluid power system ?
   (*b*) List at least 10 properties that a good hydraulic fluid should possess.
2. What types of fluid are available for hydraulic systems ? Explain, in detail, any two of them.
3. Write an engineering brief about the following hydraulic fluids :
   (*a*) Petroleum oils; (*b*) Emulsions; (*c*) Glycols, and (*d*) Phosphate ester.

□□

Chapter 3

Fluid Power Symbols

"True knowledge exists in knowing that you know nothing. And in knowing that you know nothing, that makes you the smartest of all."
– Socrates

"Any one who has never made a mistake has never tried anything new."
– Albert Einstein

"Men have become the tools of their tools."
– John Tudor

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Appreciate the need for fluid power symbols.
☑ Have a knowledge of fluid power symbols.
☑ Read and understand hydraulic and pneumatic circuit diagrams.
☑ Apply the proper graphic symbols while designing the fluid power system.

CHAPTER 3

FLUID POWER SYMBOLS

3.1. INTRODUCTION

Due to the rapid development of fluid-power applications, standard fluid power symbols and specifications are developed to facilitate communication and to provide a universal means of representing fluid-power systems. Graphic fluid power symbols, similar to symbols used in electrical circuit diagrams, are now widely used both for preparing hydraulic and pneumatic circuit diagrams and as an aid in circuit design and analysis.

The fluid power symbols illustrate flow paths, connections, and component functions. But they do not indicate operating parameters and/or construction details.

Therefore it is mandatory for any fluid power designer or engineer to have a thorough knowledge of fluid power symbols so that he/she can read, understand, design, analyse, and apply the fluid power systems. In this chapter, we shall discuss about the various graphic symbols used in hydraulic and pneumatic systems.

3.1.1. Fluid Power Symbols

- ✓ As discussed above, symbols are used to represent individual components in fluid power circuit diagrams, which identify components and their functions uniquely.
- ✓ The symbols, however, do not provide any of their construction details and operating parameters.
- ✓ The symbols explained in this chapter are based on the International Organisation for Standardisation. [Standard DIN ISO 1219]. Also these symbols conform to the American National Standards Institute (ANSI).
- ✓ The various fluid power symbols used in fluid power circuits are explained below under the eleven basic symbol classifications.[†] They are :

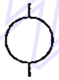
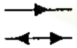
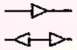
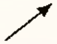
1. Pumps and motors;
2. Cylinders;
3. Directional control valves;
4. Pressure valves;
5. Flow control valves;
6. Non-return valves;
7. Operation/actuation methods;
8. Energy transmission;
9. Measuring devices;
10. Couplings, and
11. Combination of devices.

[†] This chapter presents only the graphic symbols for the various fluid power components. However, other details such as function, design, construction, and working of these components will be presented in the preceding chapters.
Readers need not bother too much about the fluid power symbols right now. Because the symbols can be better understood while studying along with their respective topics in subsequent chapters.

Now, we shall explain the above symbols, one by one, in the following sections.

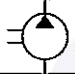
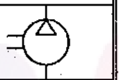
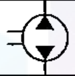
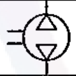
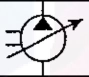
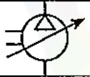
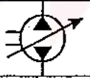
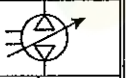
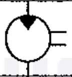
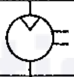
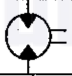
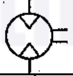
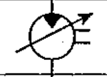
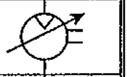
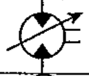
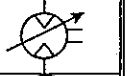
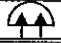
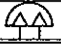
3.2. PUMPS AND MOTORS

✓ Pumps and motors are the energy producing devices to the fluid power systems. The basic general graphic symbols related to them are given below :

Circle		Represents a pump, motor, or any rotary devices.
Filled triangle		Indicates the direction of flow for hydraulic fluid (system).
Unfilled triangle		Indicates the direction of flow for pneumatic fluid (system).
Line with an arrow		Indicates the variable displacement.

✓ Table 3.1 presents the various standard symbols used for pumps and motors.

Table 3.1. Graphic symbols used for pumps and motors

Description	Symbol	Diagram	
		Hydraulic	Pneumatic
Fixed displacement, unidirectional pump	S1		
Fixed displacement, bidirectional pump	S2		
Variable displacement, unidirectional pump	S3		
Variable displacement, bidirectional pump	S4		
Fixed displacement, unidirectional motor	S5		
Fixed displacement, bidirectional motor	S6		
Variable displacement, unidirectional motor	S7		
Variable displacement, bidirectional motor	S8		
Oscillating motor	S9		

3.3. CYLINDERS

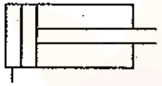
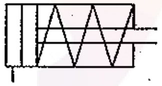
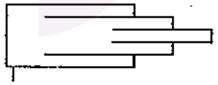
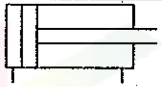
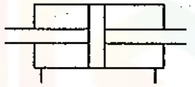
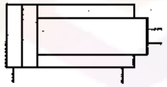
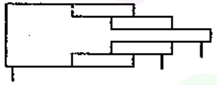
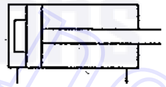
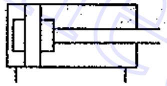
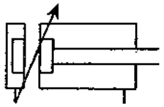
✓ The cylinders are actuators used to convert the energy of the fluid into reciprocating mechanical energy. The general symbols related to them are given below :

Outer rectangle – Represents the cylinder
Line with an arrow – Indicates the adjustable cushion

✓ Single acting cylinder has one port and double acting cylinder has 2 ports.

✓ Table 3.2 presents the various standard symbols used for cylinders.

Table 3.2. Graphic symbols used for cylinders

Description	Symbol	Diagram
Single acting cylinder, returned by external force	S10	
Single acting cylinder, with spring return	S11	
Single acting telescopic cylinder	S12	
Double acting cylinder with single piston rod	S13	
Double acting cylinder with through piston rod	S14	
Differential cylinder	S15	
Double acting telescopic cylinder	S16	
Double acting cylinder with single end position cushioning	S17	
Double acting cylinder with end position cushioning at both ends	S18	
Double acting cylinder with adjustable end position cushioning at both ends	S19	

3.4. DIRECTIONAL CONTROL VALVES

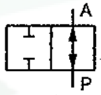
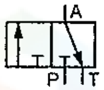
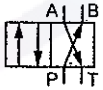
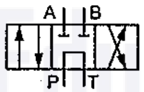
- ✓ Directional controls valves are used to determine the path of the fluid through which it should travel within a given circuit.
- ✓ Directional control valves are shown by means of several connected squares.

Number of squares – Indicates the number of switching positions possible.
Arrow within square – Indicate the flow direction.
Lines – Indicate how the ports are inter-connected in the various switching positions.

- ✓ ***Naming convention for valve :*** Number of ports / Number of switching positions "– way valve".

  Example : 4/3 valve has 4 ports and 3 switching positions.
- ✓ Table 3.3 presents the various standard symbols used for directional control valves.

Table 3.3. Graphic symbols used for directional control valves

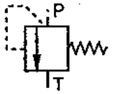
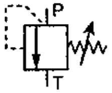
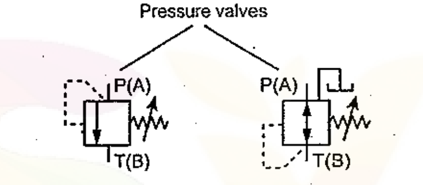
Description	Symbol	Diagram
2/2 - way valve	S20	
3/2 – way valve	S21	
4/2 – way valve	S22	
4/3 – way valve	S23	

3.5. PRESSURE VALVES

- ✓ Pressure valves are used to protect the fluid power system against over pressure.
- ✓ Pressure valves are indicated using squares.

  Arrow – Indicates flow direction
- ✓ Table 3.4 presents the various standard symbols used for pressure valves.

Table 3.4. Graphic symbols used for pressure valves

Description	Symbol	Diagram
Set pressure relief valve	S24	
Adjustable pressure relief valve	S25	
3-way pressure regulator	S26	 Pressure valves P(A) T(B) P(A) T(B) Pressure relief valve 3-way pressure regulator

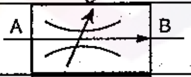
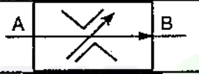
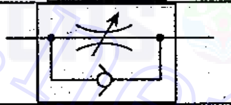
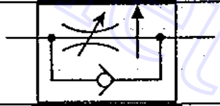
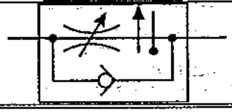
3.6. FLOW CONTROL VALVES

- ✓ Flow control valves are used to control the flow rate and hence to control the actuator speed.
- ✓ The flow control valves use the following basic general symbols :

Orifice – Flow control valves unaffected by viscosity.
Throttle – Constitute resistance in a hydraulic system.
Rectangle – Indicates flow control valve.
Diagonal arrow – Indicates that the valve is adjustable.

- ✓ Table 3.5 presents the various standard symbols used for flow control valves.

Table 3.5. Graphic symbols used for flow control valves

Description	Symbol	Diagram
Adjustable flow control valve with throttle	S27	
Adjustable flow control valve with orifice	S28	
Adjustable with bypass	S29	
Adjustable and pressure compensated with bypass	S30	
Adjustable temperature and pressure compensated	S31	

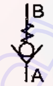
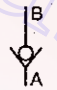
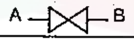
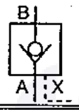
3.7. NON-RETURN VALVES

✓ The non-return valves use the following general symbols :

Circle / ball	–	Indicates the non-return valve
Open triangle	–	Indicates sealing seat
Broken line	–	Indicates the pilot control connection for the valve
Two triangles facing	–	Indicates shut-off valve

✓ Table 3.6 presents the various standard symbols used for non-return valves.

Table 3.6. Graphic symbols used for non-return valves

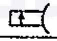
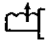
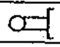
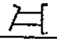
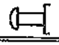
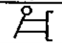
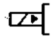
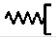
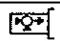
Description	Symbol	Diagram
Spring loaded non-return valve	S32	
Unloaded non-return valve	S33	
Pilot controlled non-return valve	S34	
Shut-off valve	S35	

3.8. METHODS OF OPERATION / ACTUATION

✓ The switching position of a directional control valve can be changed by various actuation methods. The symbol for the valves is elaborated by the addition of the symbol indicating the actuation method.

✓ Table 3.7 presents the various standard symbols used for methods of operation.

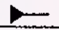
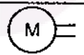
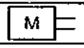
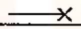
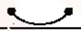
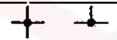
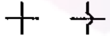
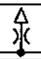
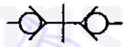
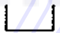
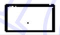
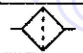
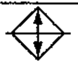
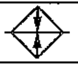
Table 3.7. Graphic symbols used for methods of operation

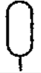
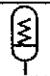
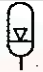
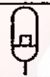
Description	Symbol	Diagram
Pressure compensator	S36	
Detent setting	S37	
Manual	S38	
Mechanical	S39	
Pedal or Treadle	S40	
Push button	S41	
Lever	S42	
Pilot pressure	S43	
Solenoid	S44	
Solenoid controlled, pilot pressure operated	S45	
Spring	S46	
Servo	S47	

3.9. ENERGY TRANSMISSION

Table 3.8 presents the various standard symbols used in circuit diagram for energy transfer and conditioning of the pressure medium.

Table 3.8. Graphic symbols used in energy transmission

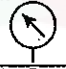
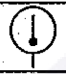
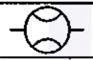
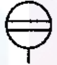
Description	Symbol	Diagram
Hydraulic pressure source	S48	
Electric motor	S49	
Non-electric drive unit	S50	
Pressure, power, return line		———
Control (pilot) line		— — — —
Drain line		- - - - - -
Plugged port	S51	
Flexible line	S52	
Line connection	S53	
Line crossing	S54	
Exhaust, continuous	S55	
Quick-acting coupling connected with mechanically opening non-return valves	S56	
Vented reservoir	S57	
Pressurized reservoir	S58	
Filter	S59	
Cooler	S60	
Heater	S61	

Description	Symbol	Diagram
Accumulator	S62	
Spring loaded accumulator	S63	
Gas charged accumulator	S64	
Weighted accumulator	S65	

3.10. MEASURING DEVICES

Table 3.9 presents the various standard symbols used for measuring devices in the circuit diagrams.

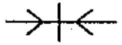
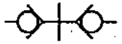
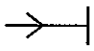
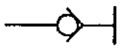
Table 3.9. Graphical symbols used for measuring devices

Description	Symbol	Diagram
Pressure gauge	S66	
Thermometer	S67	
Flowmeter	S68	
Filling level indicator	S69	

3.11. COUPLINGS

Table 3.10 presents the various standard symbols used for couplings in the circuit diagrams.

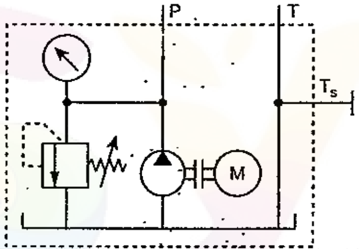
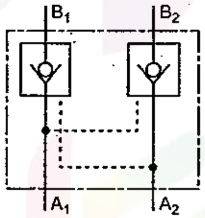
Table 3.10. Graphical symbols used for measuring devices

Description	Symbol	Diagram
Coupled without check valve	S70	
Coupled with check valve	S71	
Half of quick release-coupling without valve	S72	
Half of quick release-coupling with check valve	S73	

3.12. COMBINATION OF DEVICES

- ✓ If several devices are brought together in a single housing, the symbols for the individual devices are placed into a box made up of broken lines from which the connections are led away.
- ✓ Table 3.11 presents standard symbols for combination of devices.

Table 3.11. Graphical symbols used for combination of devices

Description	Symbol	Diagram
Hydraulic power pack	S74	
Pilot-operated double non-return valve	S75	

REVIEW AND SUMMARY

- ✓ *Graphic fluid power symbols, similar to symbols used in electrical circuit diagrams, are now widely used both for preparing hydraulic and pneumatic circuit diagrams and as an aid in circuit design and analysis.*
- ✓ *The fluid power symbols illustrate flow paths, connections, and component functions.*
- ✓ *In this chapter, the various fluid power symbols used in fluid power circuits have been presented under the following headings :*
  1. *Pumps and motors;*
  2. *Cylinders;*
  3. *Directional control valves;*
  4. *Pressure valves;*
  5. *Flow control valves;*
  6. *Non-return valves;*
  7. *Operation/actuation modes;*
  8. *Energy transmission;*
  9. *Measuring devices;*
  10. *Couplings, and*
  11. *Combination of devices.*

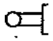
KEY TERMS ONE SHOULD REMEMBER

Fluid power symbols
Graphic symbols
Pumps
Motors
Cylinders
Directional control valves
Pressure valves
Flow control valves
Non-return valves
Measuring devices
Couplings

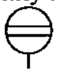
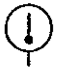
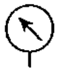
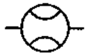
REVIEW QUESTIONS

Short Answer Type Questions

1. What are fluid power symbols ? Are they essential ? Why ?
2. How can you indicate the direction of flow (*i*) for hydraulic fluid, and (*ii*) for pneumatic fluid ?
3. Draw the graphic symbols for the following pumps :
   (*a*) Fixed displacement, bidirectional pump, and
   (*b*) Variable displacement, unidirectional pump.
4. Draw the ANSI symbols for the following motors :
   (*a*) Fixed displacement, unidirectional motor, and
   (*b*) Variable displacement, bidirectional motor.
5. What is the function of a cylinder ? Draw ANSI fluid power symbols for the following cylinder types :
   (*a*) Single acting cylinder with spring return,
   (*b*) Double acting cylinder with through piston rod,
   (*c*) Differential cylinder, and
   (*d*) Double acting telescopic cylinder.
6. Give the fluid power symbols for the 3/2 – and 4/2 – way valves.
7. Draw the graphic symbols for a pressure relief valve and a 3-way pressure regulator.
8. What are flow control valves ? Draw ANSI symbol for adjustable flow control valve with throttle.
9. Give the fluid power symbols for the following non-return valves :
   (*a*) Spring-loaded non-return valve, and
   (*b*) Pilot controlled non-return valve.
10. For the following graphic symbols shown, identify their mode of operation/actuation :

(*a*)  (*b*) (*c*) (*d*)

11. Draw ANSI symbols for the following hydraulic components :
   (*a*) Reservoir, (*b*) Filter, (*c*) Cooler, and (*d*) Accumulator.
12. The following graphic symbols are used for indicating some measuring devices. Identify them.

(*a*)  (*b*)  (*c*)  (*d*) 

13. Draw the ANSI symbols for the following coupling types :
   (*a*) Coupling with check valve, and
   (*b*) Half of quick release-coupling without valve.
14. Draw the graphic symbols for hydraulic power pack.

□□

Chapter 4

Basics of Hydraulics

> *"Water is fluid, soft, and yielding. But water will wear away rock, which is rigid and cannot yield. As a rule, whatever is fluid, soft, and yielding will overcome whatever is rigid and hard. This another paradox: what is soft is strong."*
>
> *– Lao-Tzu (600 B.C)*

> *"If A is a success in life, then A equals x plus y plus z. Work is x; y is play; and z is keeping your mouth shut."*
>
> *– Albert Einstein*

> *"It's being proven in the lab that the positive hormones you create within your own system with positive feelings do more for your regeneration than you might know."*
>
> *– Doc Childre*

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Understand the meaning of force, pressure and pressure head.

☑ Explain the different forms of pressure measurement and their relationship.

☑ Define the Pascal's law and appreciate its applications.

☑ Discuss the operation of hydraulic jack and an air-to-hydraulic pressure booster.

☑ Distinguish between laminar and turbulent flow.

☑ Appreciate the significance of Reynold's number.

☑ Apply the continuity equation, Bernoulli's equation, and energy equation to completely analyse a fluid power system.

☑ Apply the Darcy's equation to determine the head loss in a flow through pipes.

☑ Determine the functional losses in valves and fittings.

CHAPTER 4 BASICS OF HYDRAULICS

4.1. INTRODUCTION

In the Chapter 2, we have discussed the various properties desired of a hydraulic fluid and their significance. In order to understand and design a hydraulic system, the basic principles associated with the science of hydraulics are to be understood thoroughly. The basic principles of hydraulics include the concepts of force, pressure and head; concept and applications of Pascal's law; difference between laminar and turbulent flow; definition and significance of Reynolds number; and the concept and applications of Darcy's equation. It is essential for a fluid power designer or engineer to have the above basic principles of hydraulics so that to design, analyse, and apply the hydraulic systems. In this chapter, we shall review such basic principles of hydraulics.

4.2. FORCE, PRESSURE, AND HEAD

4.2.1. Force

- ✓ ***Definition :*** Force may be defined as an agent, which produces or tends to produce, destroy or tends to destroy motion.
- ✓ ***Formula :*** According to Newton's second law of motion, the applied force is directly proportional to the rate of change of momentum. Mathematically,

$$\boxed{F = m \cdot a} \qquad \dots (4.1)$$

where F = Force applied in N,

m = Mass of the body in kg, and

a = Acceleration of the body in m/s^2.

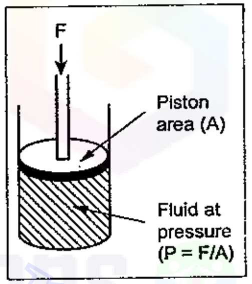


Fig. 4.1.

- ✓ ***Units :*** newtons (N)
- ✓ ***Dimensions :*** MLT^{-2}

4.2.2. Pressure

- ✓ ***Concept :*** Pressurized fluid is used in the hydraulic systems to transform the energy and consequently to produce linear or rotary motion. Pressure occurs in a fluid when it is subjected to a force.
- ✓ ***Definition :*** Pressure may be defined as force per unit area.

✓ ***Formula :*** In Fig.4.1, a force F is applied to an enclosed fluid via a piston of area A.

Then, $\boxed{\text{Intensity of pressure,} \quad P = \frac{F}{A}}$ ... (4.2)

✓ ***Units :*** newtons per square metre (N/m^2). 1 Pascal = 1 N/m^2. [Note that the most frequently used alternative SI unit is the bar; 1 bar = 10^5 N/m^2]

✓ ***Dimensions :*** $ML^{-1}T^{-2}$

4.2.3. Pressure Head

✓ The law of hydrostatics states that the pressure P of a fluid at rest increases on increasing the depth. It is also called as ***head pressure.***

✓ ***Formula :*** Consider the four vessels having the same base area A and are filled to the same height h with the same liquid of density ρ, as shown in Fig.4.2.

✓ In Fig.4.2, points A, B, C and D are at equal depths in water and therefore have identical pressure. But points a, b, c and d are at different depths and hence they have different pressures.

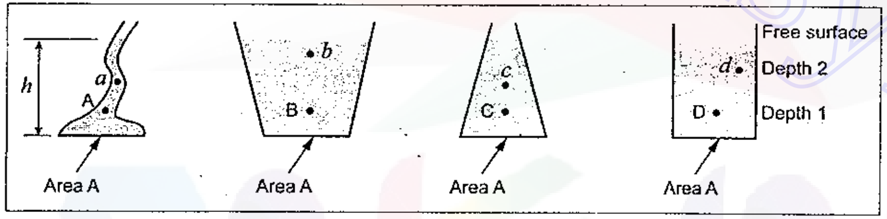


Fig. 4.2. Hydrostatic paradox

Since the pressure exerted by a fluid is dependent only on the vertical head of fluid and its mass density ρ, we can write

Pressure on bottom in each case, $\boxed{P = \rho g h}$ ... (4.3)

✓ Thus the intensity of pressure of a liquid may be expressed in the following two ways :

1. As a force per unit area (*i.e.*, N/m^2), and
2. As an equivalent static head (*i.e.*, metres, mm or cm of liquid).

4.3. ATMOSPHERIC, GAUGE AND ABSOLUTE PRESSURES

4.3.1. Atmospheric Pressure

✓ The atmosphere air exerts a normal pressure upon the surface with which it is in contact and it is known as atmospheric pressure.

✓ The atmospheric pressure is also known as ***barometric pressure.***

✓ The atmospheric pressure arises at sea level is called ***standard atmospheric pressure.***

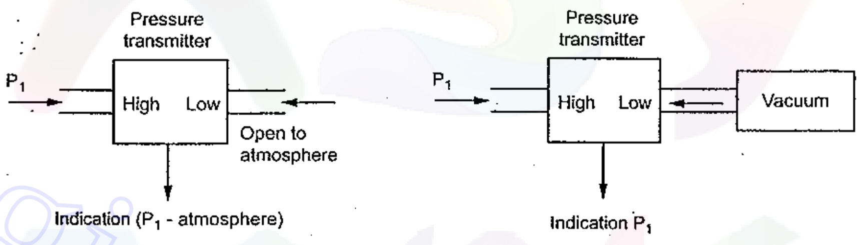
4.3.2. Gauge Pressure

✓ If the pressure is measured with reference to the atmospheric pressure, then it is called ***gauge pressure.***

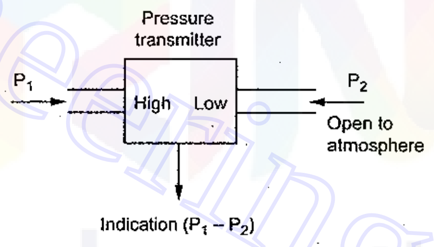
✓ It is the pressure, measured with the help of pressure measuring instrument, in which the atmospheric pressure is taken as datum. The atmospheric pressure on the scale is marked as zero. Refer Fig.4.3(a).

✓ Gauge pressure measure is universally used in most of the hydraulic and pneumatic systems.

✓ The pressure of the liquid may be above or below the atmospheric pressure. If it is below the atmospheric pressure, then the gauge is designated as ***'vacuum gauge'*** and the pressure is known as ***'vacuum pressure'.*** The vacuum (*i.e.*, negative) pressure indicates the amount by which the pressure of the liquid is below the atmospheric pressure.



(a) Gauge pressure ***(b) Absolute pressure***



(c) Differential pressure

Fig. 4.3. Different forms of pressure measurement

4.3.3. Absolute Pressure

✓ Any pressure measured above the absolute zero pressure is termed as an ***'absolute pressure'.*** In other words, the pressure measured with respect to vacuum is called an 'absolute pressure'. Refer Fig.4.3(b).

✓ Absolute pressure is important in the comparison of the compression of gases.

4.3.4. Differential Pressure

✓ Some pressure transducers or transmitters measure the pressure difference between the two parts and it is known as differential pressure. Refer Fig.4.3(*c*).

✓ The different forms of pressure measurement are depicted in Fig.4.3.

4.3.5. Relationship Between Pressures

✓ Fig.4.4 illustrates the relationship between absolute, gauge and vacuum pressures.

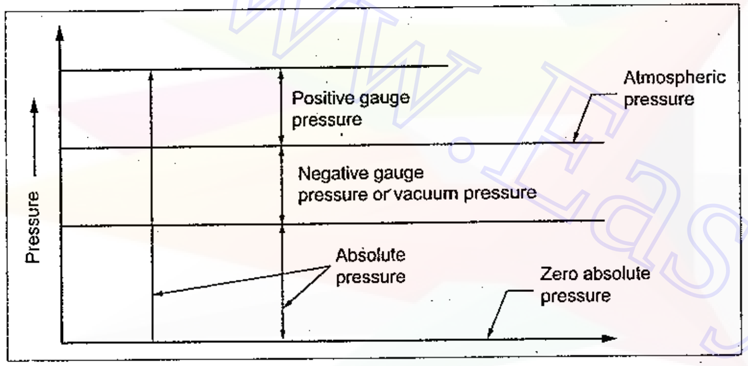


Fig. 4.4. Relationship between pressures

From Fig.4.4, it can be stated that,

$$\boxed{\text{Absolute pressure} = \text{Gauge pressure} + \text{Atmospheric pressure}} \qquad \dots (4.4)$$

and $$\boxed{\text{Vacuum pressure} = \text{Atmospheric pressure} - \text{Absolute pressure}} \qquad \dots (4.5)$$

Note Standard atmospheric pressure has the following equivalent values : 101.3 kPa; 10.3 m of water; and 760 mm of mercury.

4.4. WORK, POWER, AND ENERGY

4.4.1. Work

✓ ***Definition :*** Whenever a force acts on a body and the body undergoes a displacement in the direction of the force, then work is said to be done.

✓ ***Formula .*** $\boxed{\text{Work done} = \text{Force} \times \text{Distance moved}}$ ... (4.6)

✓ ***Units :*** newton-metre (N-m). 1 N-m = 1 J

✓ ***Dimensions :*** ML^2T^{-2}

4.4.2. Power

✓ ***Definition :*** Power is the rate of doing work or work done per unit time.

✓ ***Formula :*** $\boxed{\text{Power} = \dfrac{\text{Work done}}{\text{Time taken}}}$ ... (4.7)

✓ ***Units :*** newton metre per second (N-m/s). 1 Watt = 1 J/s = 1 N-m/s.

✓ ***Dimensions :*** ML^2T^{-3}

4.4.3. Energy

✓ ***Definition :*** Energy may be defined as the capacity to do work.

✓ The energy exists in many forms e.g., potential energy, pressure energy, kinetic energy, thermal energy, etc.

✓ ***Units :*** newton-metre (N-m). 1 Joule = 1 N-m.

✓ ***Dimensions :*** ML^2T^{-2}

Note 1. ***Torque :*** Torque is the moment created by the force (F) at the joint at the distance (*d*).

$$\therefore \qquad \boxed{\text{Torque, } T = F \cdot d} \qquad \dots (4.8)$$

We can leverage this effect and produce more torque with the same force by applying at a longer distance.

2. The amount of ***power transmitted*** by a shaft can be given by,

$$\boxed{P = \frac{2\pi NT}{60}} \qquad \dots (4.9)$$

where P = Brake power in watts,
N = Rotational speed in rpm, and
T = Torque in N-m.

3. ***Efficiency :*** Efficiency is defined as output power divided by input power.

Mathematically, $$\boxed{\eta = \frac{\text{Output power}}{\text{Input power}} \times 100} \qquad \dots (4.10)$$

4.5. PASCAL'S LAW (PRINCIPLE OF PRESSURE)

✓ ***Law :*** *Pascal's law*[†] *states that the pressure generated at any point in a confined fluid acts equally in all directions.*

✓ The law can also be stated that pressure applied to a confined fluid is transmitted undiminished in all directions.

✓ The Pascal's law reveals the underlying principle of how fluid power system work. This law applies to a fluid (*i.e.,* both liquid and gas) at rest.

✓ ***Illustration :*** The Pascal's law is illustrated in Fig.4.5 where a force F is applied on the confined liquid in the jar. This produces a pressure P at every point within the fluid, which acts with equal pressure on the inside walls of the container.

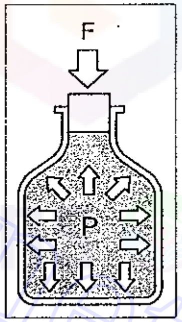


Fig. 4.5. Pascal's law demonstration in a jar

[†] This law is named after the scientist Blaise Pascal who has developed the principle of fluid power in 1648.

4.5.1. Applications of Pascal's Law

1. Bramah's Hydraulic Press

The Bramah's hydraulic press† was developed by applying the Pascal's law. In a hydraulic press, a small input force is applied to generate a large output force. That is, *the hydraulic press amplifies the hydraulic force in the hydraulic systems.*

Working

Consider two oil containers both in cylindrical form and connected together contain some oil, as shown in Fig.4.6. Both the cylinders have a piston having different diameters says D_1 and D_2 respectively, where D_1 is smaller than D_2.

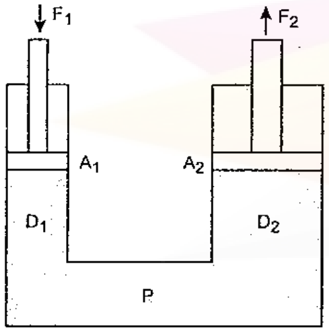


Fig. 4.6. Principle of Bramah's press

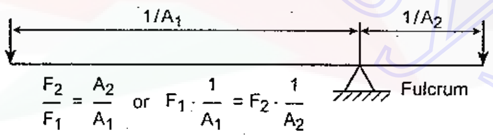


Fig. 4.7. A hydraulic lever

If a force F_1 is applied to the small-diameter piston, then this will produce an oil pressure P_1 at the bottom of the piston 1. Now this pressure is transmitted through the oil to the large-diameter piston 2. Because the piston 2 has a larger area (A_2), the pressure at the bottom of the piston 2 will be P_2. Now this pressure P_2 will push up the piston 2 to create an output force F_2.

We know that according to Pascal's law, $P_1 = P_2$

or $$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

or $$\boxed{\frac{F_2}{F_1} = \frac{A_2}{A_1}} \quad \text{... (4.11)}$$

where A_1 = Area of the smaller piston $= \frac{\pi}{4} D_1^2$, and

A_2 = Area of the larger piston $= \frac{\pi}{4} D_2^2$.

[†] It is named after an English Engineer Joseph Bramah who has developed it in 1795.

Since $A_2 > A_1$ (*i.e.*, $A_2/A_1 > 1$), therefore F_2 will be higher than F_1. In other words, the hydraulic press amplifies the hydraulic force.

It may be noted that the hydraulic press arrangement shown in Fig.4.6 is equivalent to a mechanical lever as shown in Fig.4.7 with the length of the lever arms being inversely proportional to the piston areas.

2. Transmission of Displacement (Hydraulic Jack)

To lift the load F_2 by a distance s_2, the piston P_1 must displace specific quantity of liquid by moving by a distance s_1, as shown in Fig.4.8.

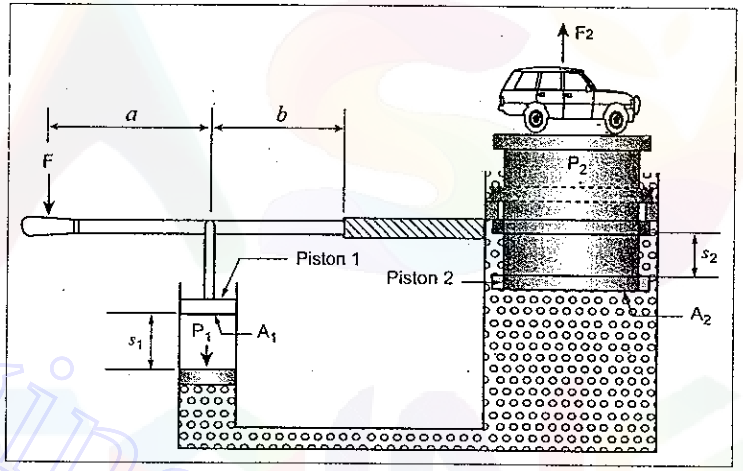


Fig. 4.8. Application of Pascal's law to displacement transfer

Volume of oil displaced, $V_1 = s_1 \cdot A_1$ and $V_2 = s_2 \cdot A_2$

Since the displacement volume is identical,

$$V_1 = V_2$$

$$\therefore \quad s_1 \cdot A_1 = s_2 \cdot A_2$$

or $$\frac{s_2}{s_1} = \frac{A_1}{A_2} \quad \text{... (4.12)}$$

Combining equations (4.11) and (4.12), we get

$$\boxed{\frac{F_2}{F_1} = \frac{s_1}{s_2} = \frac{A_2}{A_1}} \quad \text{... (4.13)}$$

From the equation (4.13), one can conclude that in a hydraulic press, *the output force is greater than the input force, but the output movement will be lesser than the input movement.*

The equation (4.13) can be rewritten as $F_1 s_1 = F_2 s_2$ ... (4.14)

We know that energy is the product of force and the distance moved by the force. Thus from equation (4.4), we can state that the *energy input to the hydraulic press equal the energy output from the press.*

3. Air-to-Hydraulic Pressure Booster

- ✓ ***Use :*** The air-to-hydraulic pressure booster is a device used for converting compressed air into the higher hydraulic pressure, which is required for operating hydraulic cylinders. Such device can be found in various applications such as booster-powered riveting pressure, and booster-powered clamps on milling machines.
- ✓ ***Construction :*** Fig.4.9 illustrates an air-to-hydraulic pressure booster arrangement, which is commonly employed to clamp workpiece to a machine tool table.

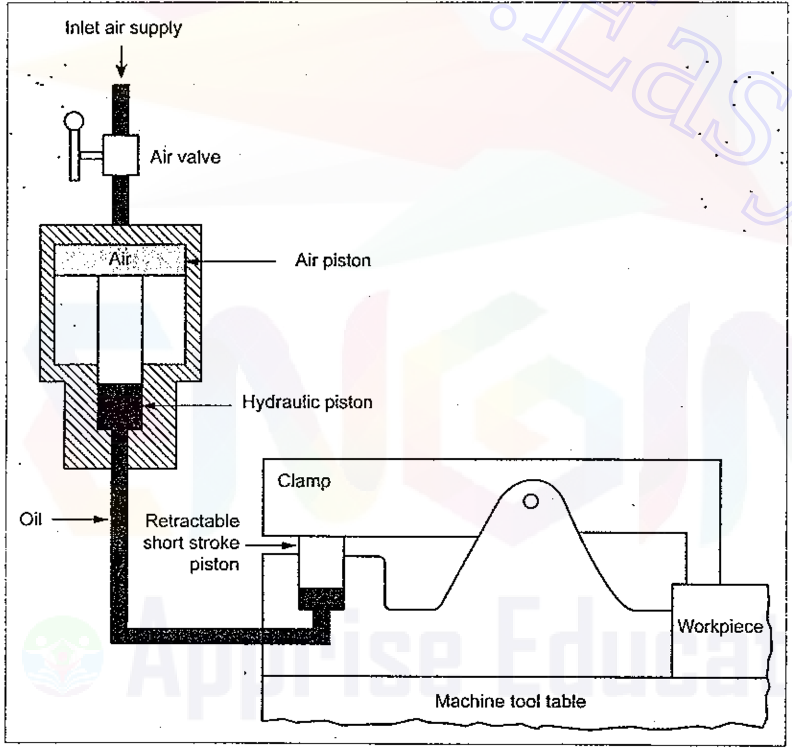


Fig. 4.9. Air-to-hydraulic pressure booster (used to clamp a workpiece to a machine tool table)

Working : If the air piston (having a area A_1) is subjected to air pressure P_1, then the air will produce a force F_1 on the hydraulic cylinder piston. If the area of the hydraulic piston is A_2 (such that $A_2 << A_1$), then the hydraulic discharge oil pressure will be P_2. Now, as per Pascal's law, this oil pressure P_2 will be used for clamping a workpiece to a machine tool table, as shown in Fig.4.9.

The pressure ratio of an air-to-hydraulic pressure can be calculated by using the relation :

$$\boxed{\text{Pressure ratio} = \frac{\text{Output oil pressure } (P_2)}{\text{Input air pressure } (P_1)} = \frac{\text{Area of air piston } (A_1)}{\text{Area of hydraulic piston } (A_2)}} \quad \ldots (4.15)$$

4. Pressure Transfer

Pressure P_1 produces force F_1 on the area A_1, which is transferred through the piston rod to the other end with force F_2, acting on area A_2, and producing pressure P_2. This is illustrated in Fig.4.10.

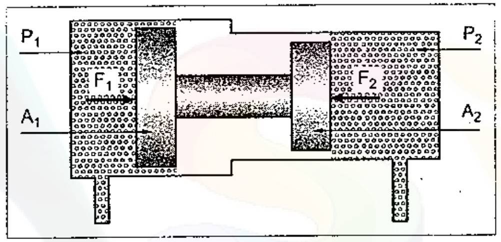


Fig. 4.10. Application of Pascal's law to pressure transfer

We know that, $$P = \frac{F}{A}$$

$$F_1 = P_1 \cdot A_1 \text{ and } F_2 = P_2 \cdot A_2$$

Since F_1 and F_2 are equal, $$P_1 \cdot A_1 = P_2 \cdot A_2$$

or $$P_2 = \frac{P_1 \times A_1}{A_2} \text{ and } A_2 = \frac{P_1 \times A_1}{P_2}$$

4.6. FLUID FLOW

As we know, the hydraulic system is concerned with the flow of a liquid through a pipe. The two important types of flow are :

1. Laminar flow, and 2. Turbulent flow.[†]

4.6.1. Laminar Flow

- ✓ A laminar flow is one in which paths taken by the individual particles do not cross one another and move along well defined paths, as shown in Fig.4.11.
- ✓ The laminar flow is characterized by the fluid flowing in smooth layers of laminae.
- ✓ This type of flow is also known as ***streamline*** or ***viscous flow,*** because the particles of fluid moving in an orderly manner and retaining the same relative positions in successive cross-sections.

[†] In fact, these fluid flows are first demonstrated by Osborne Reynold's in 1883 through an experiment. For more details on the Reynold's experiment, refer Article 3, Appendix I.

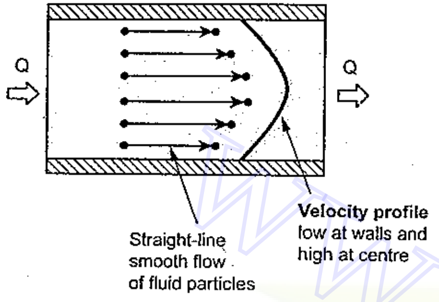

Q
Q
Straight-line smooth flow of fluid particles
Velocity profile low at walls and high at centre

Fig. 4.11. Laminar flow

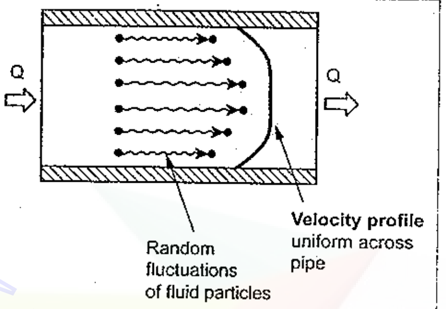

Q
Q
Random fluctuations of fluid particles
Velocity profile uniform across pipe

Fig. 4.12. Turbulent flow

✓ ***Examples :*** (*i*) Flow of oil in measuring instruments.

(*ii*) Flow of blood in veins and arteries.

(*iii*) Rise of water in plants through their roots.

4.6.2. Turbulent Flow

✓ A turbulent flow is that flow in which fluid particles move in a zig-zag way, as shown in Fig.4.12.

✓ The turbulent flow is characterized by continuous small fluctuations in the magnitude and direction of the velocity of the fluid particles.

✓ ***Causes :*** The turbulence in the fluid may cause :

(*i*) More resistance to flow,

(*ii*) Greater energy loss, and

(*iii*) Increased fluid temperature due to greater energy loss.

✓ ***Examples :*** High velocity flow in a pipe of large size. Nearly all fluid flow problems encountered in engineering practice have a turbulent character.

4.7. REYNOLD'S NUMBER

✓ Reynolds from his experiments found that the nature of flow in a closed pipe depends upon the following factors :

(*i*) Diameter of the pipe (D),

(*ii*) Density of the liquid (ρ),

(*iii*) Viscosity of the liquid (μ), and

(*iv*) Velocity of flow (V).

✓ By combining the above variables, Reynolds determined a non-dimensional quantity equal to $\frac{\rho V D}{\mu}$ which is known as ***Reynolds number (Re).***

$$\therefore \quad \text{Reynolds number, Re} = \frac{\rho V D}{\mu} = \frac{V D}{\nu} \quad \left[\because \nu = \frac{\mu}{\rho}\right] \qquad \ldots (4.16)$$

✓ Laminar and turbulent flows are characterised on the basis of Reynolds number.

1. *If Reynolds number (Re) < 2000, then the flow in pipes is **laminar.***
2. *If Reynolds number (Re) > 4000, then the flow in pipes is **turbulent.***
3. If Reynolds number is between 2000 and 4000, then the flow in pipes is unpredictable.

✓ Since turbulent flow results in greater losses, therefore hydraulic systems should be designed to operate in the laminar flow region.

✓ The turbulent flow can be converted into laminar flow by either reducing the velocity of liquid or by increasing the pipe diameter.

4.8. FLOW RATE OR DISCHARGE

✓ Flow rate (or discharge) is the volume of the liquid flowing through a pipe in a specific period of time.

✓ As shown in Fig.4.13, the flow rate can be calculated using the relation,

$$\boxed{Q = \frac{V}{t}} \qquad \ldots (4.17)$$

where Q = Flow rate in m^3/s,

V = Volume of the liquid in m^3, and

t = Time in sec.

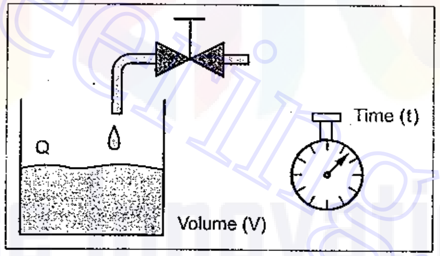


Fig. 4.13. Flow rate

✓ The flow rate can also be calculated by using the relation,

$$\boxed{Q = A \cdot V} \qquad \ldots (4.18)$$

where A = Area of cross-section of the pipe in m^2, and

V = Average velocity of the liquid in m/s.

4.9. CONTINUITY EQUATION

The continuity equation is based on the principle of conservation of mass. It states as follows :

"If no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be same."

Illustrations : Consider three cross-sections of a pipe as shown in Fig.4.14.

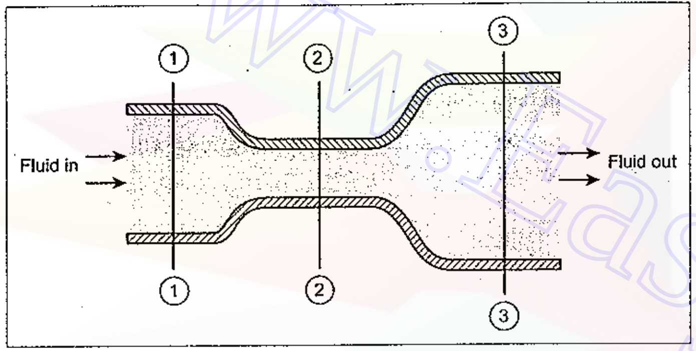


Fig. 4.14. Fluid flow through a pipe

Let A_1 = Area of section 1–1,

V_1 = Velocity of the fluid at section 1–1,

ρ_1 = Density of the fluid at section 1–1,

A_2, V_2, ρ_2 = Corresponding values at section 2–2, and

A_3, V_3, ρ_3 = Corresponding values at section 3–3.

Applying the law of conservation of mass, we have

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2 = \rho_3 A_3 V_3$$

In case of incompressible fluid,

$$\rho_1 = \rho_2 = \rho_3$$

$$\therefore \quad \boxed{A_1 V_1 = A_2 V_2 = A_3 V_3} \qquad \dots (4.19)$$

Equation (4.19) is called the continuity equation for incompressible fluids.

4.10. FLUID ENERGY IN MOTION

The total fluid energy in motion may be classified into three types. They are :

1. Potential energy (or potential head) : This is due to configuration or position above some suitable datum line. It is denoted by z.

2. Kinetic energy (or velocity head) : This is due to the velocity of flowing fluid. It is measured as $V^2/2g$ where V is the velocity of flow.

3. Pressure energy (or pressure head) : This is due to the pressure of liquid. It is measured as P/w where P is the pressure and w is the weight density of the liquid.

$$\therefore \text{ Total energy of a liquid in motion, } \quad \boxed{E = z + \frac{V^2}{2g} + \frac{P}{w}} \qquad \dots (4.20)$$

4.11. BERNOULLI'S EQUATION

- ✓ Bernoulli equation states as follows :

  "In an ideal, incompressible fluid when the flow is steady and continuous, the sum of potential energy, kinetic energy and pressure energy is constant across all cross sections of the pipe."

- ✓ For the incompressible fluid flowing through a non-uniform pipe shown in Fig.4.15, the Bernoulli's equation can be written as,

$$\boxed{z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w}} \qquad \dots (4.21)$$

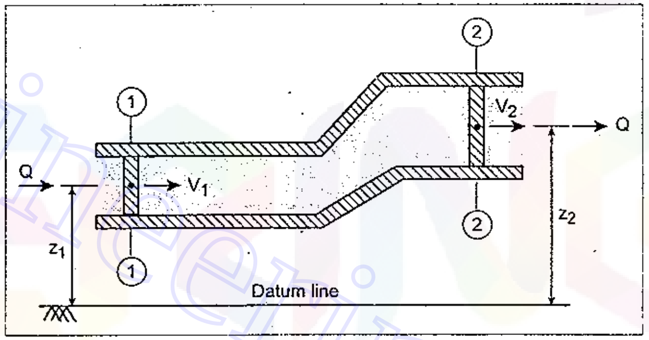


Fig. 4.15. Flow through pipe

4.12. ENERGY EQUATION

Bernoulli's equation stated earlier was based on the assumption that fluid is ideal (i.e., non-viscous) and therefore frictionless. But practically all fluids are real (i.e., viscous) and therefore there are always some losses during the fluid flow. These energy losses have to be taken into consideration in the application of Bernoulli's equation which gets modified for real fluids as follows :

$$z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w} + H_L \qquad \dots (4.22)$$

where H_L = Loss of energy between sections 1 and 2.

The equation (4.22) is known as ***energy equation.*** This is also called as the ***modified Bernoulli's equation.***

Note The knowledge of continuity equation, Bernoulli's equation, and energy equation are very important to keep all energy losses in a fluid power system to a minimum acceptable level. It aids in the proper selection of the sizes of the pipes and fittings that make up the system. The knowledge is also required to perform a complete analysis of a fluid power system.

4.13. LOSS OF ENERGY IN PIPES

As discussed earlier, when liquid flows in a pipe, there will be some energy loss. This loss of energy may be classified as follows :

1. Major energy losses

   This loss is due to friction.

2. Minor energy losses

   These losses are due to :

   (*i*) Losses in valves and pipe fittings,

   (*ii*) Sudden enlargement/contraction of pipe,

   (*iii*) Bend in pipe, and

   (*iv*) An obstruction in pipe.

4.14. DARCY'S EQUATION

✓ The major energy losses i.e., the energy losses due to friction in the pipe can be calculated by using Darcy's equation.

✓ The Darcy's equation for the loss of head due to friction in pipes is as follows :

$$\boxed{H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)} \qquad \ldots (4.23)$$

where H_L = Loss of head due to friction in pipe in m,

f = Friction factor,

L = Length of pipe in m,

D = Inside diameter of the pipe in m,

V = Average velocity of liquid in m/s, and

g = Acceleration due to gravity in m/s^2.

✓ The Darcy's equation holds good for both laminar and turbulent flow provided a proper value of friction factor 'f' is evaluated.

4.14.1. Frictional Losses in Laminar Flow

For laminar flow, the friction factor 'f' is function of Reynolds number only and is given by,

$$\boxed{f = \frac{64}{Re}} \qquad \ldots (4.24)$$

Substituting equation (4.24) into equation (4.23), we get

$$\boxed{H_L = \frac{64}{Re}\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)} \qquad \ldots (4.25)$$

The above equation is known as the ***Hagen-Poiseuille equation,*** which is valid only for laminar flow.

4.14.2. Frictional Losses in Turbulent Flow

✓ Unlike for laminar flow, the friction factor 'f' for turbulent flow is a function of Reynolds number as well as the relative roughness of the pipe.

✓ The ***relative roughness*** is defined as the pipe inside surface roughness (ε) divided by the inside diameter of the pipe (D).

$$\therefore \quad \boxed{\text{Relative roughness} = \frac{\varepsilon}{D}} \qquad \ldots (4.26)$$

✓ In equation (4.26), the 'ε' is called the ***absolute roughness.*** Table 4.1 gives typical values of absolute roughness for various types of pipes. For a given pipe, the appropriate 'ε' value may be selected using the Table 4.1.

Table 4.1. Typical values of absolute roughness

Types of pipe	Absolute roughness ε (mm)
Glass or plastic	Smooth
Drawn tubing	0.0015
Commercial steel or wrought iron	0.046
Asphalted cast iron	0.12
Galvanized iron	0.15
Cast iron	0.26
Riveted steel	1.8

✓ Once we calculate the relative roughness (ε/D) and Reynolds number, we can determine the friction factor for use in Darcy's equation by using the Moody diagram. The Moody diagram is presented in Fig.4.16. The Moody diagram contains many curves. The curves indicate the value of friction factor as a function of Reynolds number and relative roughness.

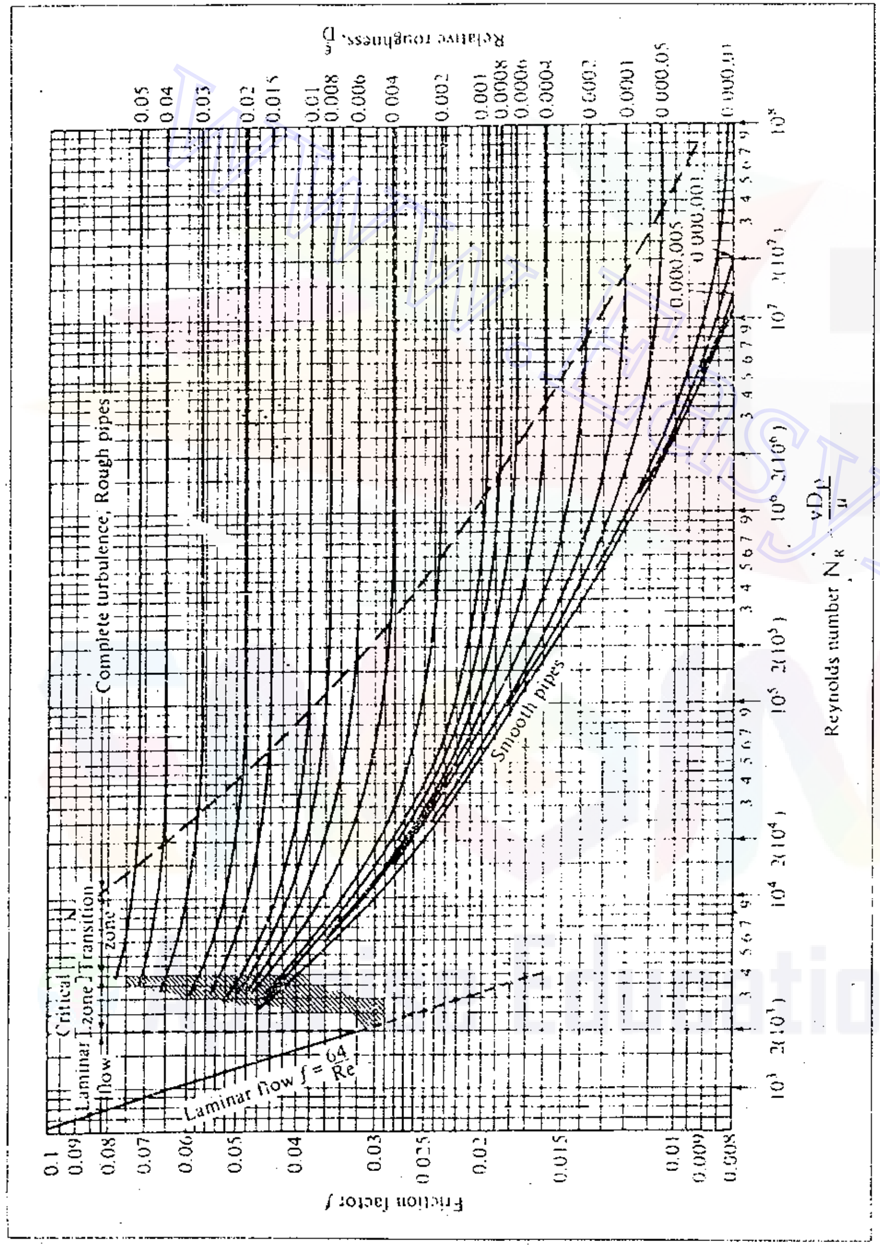


Fig. 4.16. Moody diagram to obtain the friction factor

4.15. LOSSES IN VALVES AND FITTINGS

✓ The loss of head in the various valves and fittings (such as tees, elbows, and bends) is given by the relation :

$$\boxed{H_L = K\left(\frac{V^2}{2g}\right)} \quad \ldots (4.27)$$

where K = Constant of proportionality called 'the ***K-factor***'.

✓ The value of K-factor depends on the type of valves and pipe fittings. Table 4.2 gives typical K-factor values for several common types of valves and fittings.

✓ If the loss of head H_L is known, it can be expressed into equivalent pressure drop by using the relation,

$$\boxed{\Delta P = H_L \times w_{oil}} \quad \ldots (4.28)$$

where w_{oil} = Weight density of oil flowing through valves and fittings.

Table 4.2. K-factors of common valves and fittings

Valve or Fitting		K-Factor
Globe valve :	Wide open	10.0
	½ open	12.5
Gate valve :	Wide open	0.19
	¾ open	0.90
	½ open	4.5
	¼ open	24.0
Return bend		2.2
Standard tee		1.8
Standard elbow		0.9
45° Elbow		0.42
90° Elbow		0.75
Ball check valve		4.0

Note

1. The most commonly used flow measuring devices are rotameter, turbine flowmeter, orifice flowmeter, and sight flow indicator.
2. The two important pressure measuring devices are Bourdon gauge and Schrader gauge.

SOME ILLUSTRATIVE EXAMPLE PROBLEMS

✓ For better understanding of the basic principles of hydraulics discussed so far, some simple numerical problems have been presented below.

On Force, Pressure, and Head

Example 4.1 *(a) Find the pressure at a depth of 10 m below the free surface of water in a reservoir.*

(b) Find the height of water column corresponding to a pressure of 70 kPa.

(a) Given Data : $h = 10$ m.

☺ ***Solution :*** We know that,

$$P = \rho g h$$
$$= 1000 \times 9.81 \times 10 \qquad [\because \rho_{water} = 1000 \text{ kg/m}^3]$$
$$= 0.981 \times 10^5 \text{ N/m}^2 = \mathbf{0.981 \text{ bar}}$$ **Ans.** ☜

(b) Given Data : $P = 70 \text{ kPa} = 70 \times 10^3 \text{ N/m}^2$.

☺ ***Solution :*** We know that,

$$P = \rho g h$$

or $$70 \times 10^3 = 1000 \times 9.81 \times h$$

or $$h = \mathbf{7.135 \text{ m of water column}}$$ **Ans.** ☜

On Atmospheric, Gauge, and Absolute Pressures

Example 4.2 *If a mercury barometer reads 700 mm and Bourdon gauge at a point in a flow system reads 500 kPa, what is the gauge, atmospheric, and absolute pressures at the point. Take specific gravity of mercury = 13.6.*

☺ ***Solution : (i) Gauge pressure :***

We know that the gauge pressure is the pressure measured with the help of pressure measuring instrument – Bourdon gauge.

Therefore the gauge pressure = **500 kPa** or **5 bar** **Ans.** ☜

(ii) Atmospheric pressure :

Barometer reading (atmospheric pressure) = 700 mm of mercury

or $$h = 700 \times 13.6 \text{ mm of water}$$
$$= \frac{700 \times 13.6}{1000} = 9.52 \text{ m of water}$$

$\therefore$ $$\text{Atmospheric pressure, } P = \rho g h$$
$$= 1000 \times 9.81 \times 9.52$$
$$= \mathbf{93.39 \text{ kN/m}^2}$$ **Ans.** ☜

(iii) Absolute pressure : We know that,

$$\text{Absolute pressure} = \text{Gauge pressure} + \text{Atmospheric pressure}$$
$$= 500 + 93.39 = \mathbf{593.39 \text{ kN/m}^2}$$ **Ans.** ☜

Example 4.3 *Convert – 3.5 kPa pressure to an absolute pressure in kPa.*

Given Data : $P_{gauge} = -3.5$ kPa

☺ ***Solution :*** $$\text{Absolute pressure} = \text{Gauge pressure} + \text{Atmosphere pressure}$$
$$= -3.5 + 101.3 = \mathbf{97.8 \text{ kPa}}$$ **Ans.** ☜

On Work and Power

Example 4.4 *A person applied 200 N force to move a load 2.5 m in 90 s.*

(a) How much work is done ?

(b) What is the power exerted by the person ?

Given Data : $F = 200$ N ; $d = 2.5$ m ; $t = 90$ s.

☺ ***Solution :***

(a) $$\text{Work done} = F \cdot d = 200 (2.5) = \mathbf{500 \text{ N-m}}$$ **Ans.** ☜

(b) $$\text{Power} = \frac{F \cdot d}{t} = \frac{200 (2.5)}{90} = \mathbf{5.55 \text{ watt}}$$ **Ans.** ☜

On Application of Pascal's Law

Example 4.5 *The diameters of plunger and ram of an hydraulic press (shown in Fig.4.17) are 50 mm and 125 mm respectively. Find the weight lifted by the hydraulic press when the force applied at the plunger is 750 N.*

Given Data : $D_1 = 50$ mm ; $D_2 = 125$ mm ;

$F_1 = 750$ N.

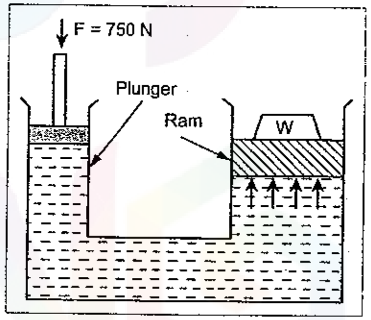


Fig. 4.17.

☺ ***Solution :*** $$\text{Area of plunger, } A_1 = \frac{\pi}{4} D_1^2$$
$$= \frac{\pi}{4} (50 \times 10^{-3})^2 = 1.963 \times 10^{-3} \text{ m}^2$$

and $$\text{Area of ram, } A_2 = \frac{\pi}{4} D_2^2 = \frac{\pi}{4} (125 \times 10^{-3})^2 = 0.01227 \text{ m}^2$$

We know that for a hydraulic press,

$$\frac{F_2}{F_1} = \frac{A_2}{A_1} \qquad \text{... [From equation (4.11)]}$$

or $$\frac{F_2}{750} = \frac{0.01227}{1.963 \times 10^{-3}}$$

or Weight lifted by the hydraulic press, $F_2 = \mathbf{4.688 \text{ kN}}$ **Ans.** ☜

Example 4.6 *For the pressure booster of Fig.4.18, the following data are given :*

Inlet oil pressure (P_1) = 0.85 MPa ; Air piston area (A_1) = 0.025 m² ;

Oil piston area (A_2) = 0.0015 m² ; Load piston area (A_3) = 0.015 m².

Determine the load-carrying capacity F of the system.

Given Data : $P_1 = 0.85$ MPa $= 0.85 \times 10^6$ N/m²; $A_1 = 0.025$ m²; $A_2 = 0.0015$ m²; $A_3 = 0.015$ m².

☺ ***Solution :*** Refer Fig.4.18. Let us first find the booster discharge pressure P_2.

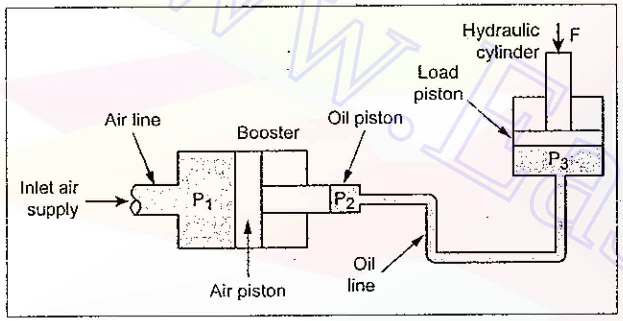


Fig. 4.18. An air-to-hydraulic booster system

We know that, Booster input force = Booster output force

$$P_1 A_1 = P_2 A_2$$

or
$$P_2 = \frac{P_1 A_1}{A_2} = \frac{(0.85 \times 10^6)\,(0.025)}{(0.0015)} = 14.17 \times 10^6 \text{ N/m}^2$$

According to Pascal's law, $P_3 = P_2 = 14.17 \times 10^6$ N/m²

∴ The load-carrying capacity, $F = P_3 A_3 = (14.17 \times 10^6)\,(0.015)$

$= $ **212.5 kN Ans.** ☜

On Reynolds Number and Fluid Flow

Example 4.7 *The kinematic viscosity of a hydraulic oil is 0.9 stroke. If it is flowing in a 35 mm diameter pipe at a velocity of 4 m/s, what is the Reynolds number ? Is the flow laminar or turbulent ?*

Given Data : $\nu = 0.9$ stroke $= 0.9$ cm²/s $= 0.9 \times 10^{-4}$ m²/s ; D = 35 mm ; V = 4 m/s.

☺ ***Solution :*** We know that,

$$\text{Reynolds number, Re} = \frac{V\,D}{\nu}$$

or
$$\text{Re} = \frac{4\,(35 \times 10^{-3})}{0.9 \times 10^{-4}} = \mathbf{1555.55}$$ **Ans.** ☜

Since Re < 2000, the flow is *laminar.* **Ans.** ☜

On Flow Rate and Continuity Equation

Example 4.8 *A hydraulic pump delivers fluid at 50 Lpm (i.e., litres per minute) through a 30 mm diameter pipe. Determine the fluid velocity.*

Given Data : $Q = 50 \text{ Lpm} = \dfrac{50 \times 10^{-3}}{60}$ m³/s ; D = 30 × 10⁻³ m.

☺ ***Solution :*** Area of pipe, $A = \dfrac{\pi}{4}\,(30 \times 10^{-3})^2 = 7.07 \times 10^{-4}$ m²

We know that, Discharge, $Q = A \times V$

or
$$\frac{50 \times 10^{-3}}{60} = (7.07 \times 10^{-4})\,V$$

or Fluid velocity, $V = $ **1.179 m/s Ans.** ☜

Example 4.9 *The diameters of a pipe at the sections 1–1 and 2–2 are 100 mm and 150 mm respectively. If the velocity of water flowing through the pipe at section 1–1 is 3.5 m/s, find :*

(a) Discharge through the pipe, and

(b) Velocity of water at section 2–2.

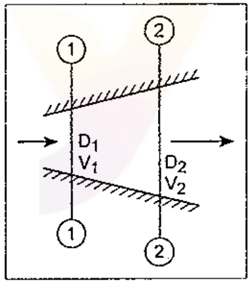


Fig. 4.19.

Given Data : $D_1 = 100$ mm ; $D_2 = 150$ mm ; $V_1 = 3.5$ m/s.

☺ ***Solution :*** Refer Fig.4.19.

$$A_1 = \frac{\pi}{4}\,(100 \times 10^{-3})^2 = 7.85 \times 10^{-3} \text{ m}^2; \quad A_2 = \frac{\pi}{4}\,(150 \times 10^{-3})^2 = 0.0177 \text{ m}^3/\text{s}$$

(a) Discharge through the pipe (Q) :

$$Q = A_1 V_1 = (7.85 \times 10^{-3})\,3.5 = \mathbf{0.0275 \text{ m}^3/\text{s}}$$ **Ans.** ☜

(b) Velocity of water at section 2–2 (v_2) :

Using the continuity equation, we get

$$A_1 V_1 = A_2 V_2$$

or
$$V_2 = \frac{A_1 V_1}{A_2} = \frac{(7.85 \times 10^{-3})\,3.5}{0.0177} = \mathbf{1.552 \text{ m/s}}$$ **Ans.** ☜

On Bernoulli's Equation

Example 4.10 *Fluid is flowing through a tapering pipe having diameters 50 mm and 25 mm at sections 1 and 2 respectively. The discharge through the pipe is 7.5 Lps (i.e., litres per second). The section 1 is 3 m above datum and section 2 is 1.25 m above datum. If the pressure at section 1 is 200 kPa, find the pressure at section 2. The specific gravity of the fluid is 0.9.*

Given Data : $D_1 = 50$ mm ; $D_2 = 25$ mm ; $Q = 7.5$ Lps $= 7.5 \times 10^{-3}$ m³/s ;

$z_1 = 3$ m ; $z_2 = 1.25$ m ; $P_1 = 200$ kPa $= 300 \times 10^3$ N/m² ; Specific gravity = 0.9.

☺ ***Solution :*** Refer Fig.4.20,

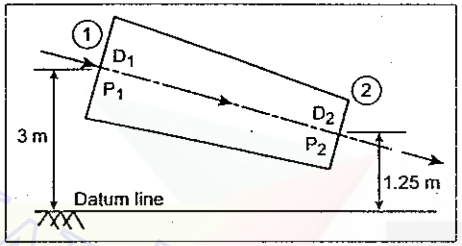


Fig. 4.20.

$$A_1 = \frac{\pi}{4}(50 \times 10^{-3})^2 = 1.963 \times 10^{-3} \text{ m}^2;$$

$$A_2 = \frac{\pi}{4}(25 \times 10^{-3})^2 = 4.91 \times 10^{-4} \text{ m}^2.$$

$$\text{Specific gravity} = \frac{w_{fluid}}{w_{water}}$$

$$\therefore \text{Weight density of fluid, } w = 0.9 \times 9810$$

$$= 8829 \text{ N/m}^3$$

We know that, $Q = A_1 V_1 = A_2 V_2$

$$\therefore \quad V_1 = \frac{Q}{A_1} = \frac{7.5 \times 10^{-3}}{1.963 \times 10^{-3}} = 3.82 \text{ m/s}$$

and
$$V_2 = \frac{Q}{A_2} = \frac{7.5 \times 10^{-3}}{4.91 \times 10^{-4}} = 15.28 \text{ m/s}$$

Now applying the Bernoulli's equation at sections 1 and 2, we get

$$z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w}$$

or
$$3 + \frac{(3.82)^2}{(2 \times 9.81)} + \frac{(200 \times 10^3)}{8829} = 1.25 + \frac{(15.28)^2}{(2 \times 9.81)} + \frac{P_2}{8829}$$

or Pressure at section 2, P_2 = **116.95 kPa (gauge)** **Ans.** ☜

On Darcy's Equation

Example 4.11 ***The kinematic viscosity of a hydraulic oil is 100 cS. If it is flowing in a 20 mm diameter commercial steel pipe, find the friction factor in each case.***

(a) The velocity is 4.6 m/s.

(b) The velocity is 14 m/s.

Given Data : $\nu = 100$ cS $= 1$ stroke $= 1 \times 10^{-4}$ m²/s ; $D = 20$ mm.

☺ ***Solution :***

(a) When the velocity $v = 4.6$ m/s :

First, find the Re number.

$$\text{Re} = \frac{V\,D}{\nu} = \frac{(4.6)(20 \times 10^{-3})}{1 \times 10^{-4}} = 920$$

Since Re < 2000, therefore the flow is laminar.

We know that friction factor for the laminar flow,

$$f = \frac{64}{\text{Re}} = \frac{64}{920} = \mathbf{0.0695} \quad \textbf{Ans.}$$ ☜

Note The friction factor for the laminar flow can also be obtained using the Moody diagram.

(b) When the velocity v = 14 m/s :

$$\text{Reynolds number, Re} = \frac{V\,D}{\nu} = \frac{14\,(20 \times 10^{-3})}{1 \times 10^{-4}} = 2{,}800$$

Since Re > 2000, therefore the flow is turbulent.

For the turbulent flow, first we have to find the value of relative roughness (ε/D).

From Table 4.1, for commercial steel pipe, ε = 0.046 mm.

$$\therefore \quad \text{Relative roughness} = \frac{\varepsilon}{D} = \frac{0.046}{20} = 0.0023$$

Now using the Moody diagram (Fig.4.16), by locating the Re and ε/D values, we get the projected friction factor value as **0.034 Ans.** ☜

Example 4.12 ***For the system of Example 4.7, find the loss of head due to friction for a 100 m length of smooth pipe. Also express the head loss in units of bars. The oil has a specific gravity of 0.90.***

Given Data : Re = 1555.55 ; D = 35 mm ; $v = 4$ m/s ; L = 100 m ;

Specific gravity = 0.90.

☺ ***Solution :*** Since the flow is laminar, the head loss due to friction can be calculated by using the Hagen-Poiseuille equation,

$$\therefore \quad H_L = \frac{64}{\text{Re}}\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

$$= \frac{64}{1555.55}\left(\frac{100}{35 \times 10^{-3}}\right)\left(\frac{4^2}{2 \times 9.81}\right) = \mathbf{95.86 \text{ m of oil}} \quad \textbf{Ans.}$$ ☜

The pressure drop is $\Delta P = w\,(\text{N/m}^3) \times H_L\,(\text{m})$

$$w_{oil} = \text{Specific gravity} \times w_{water} = 0.9 \times 9810 = 8829 \text{ N/m}^3$$

$$\therefore \quad \Delta P = 8829 \times 95.86 = 846{,}348 \text{ Pa} = \mathbf{8.46 \text{ bars}} \quad \textbf{Ans.}$$ ☜

On Losses in Valves and Fittings

Example 4.13 ***What is the head loss (in units of bars) across a 40 mm wide open gate valve when oil ($S_g = 0.90$) flows through it at a rate of 0.03 m³/s ?***

Given Data : D = 40 mm ; Wide open gate valve ;

$S_g = 0.90$ or $w_{oil} = S_g \times w_{water} = 0.9 \times 9810 = 8829$ N/m^3; $Q = 0.015$ m^3/s.

☺ **Solution :**

$$A = \frac{\pi}{4}(40 \times 10^{-3})^2 = 1.256 \times 10^{-3} \text{ m}^2$$

$$\text{Velocity, } V = \frac{Q}{A} = \frac{0.015}{1.256 \times 10^{-3}} = 11.94 \text{ m/s}$$

From Table 4.2, the K-factor for wide open gate valve = 0.19.

We know that the head losses in valves and fittings,

$$H_L = K\left(\frac{V^2}{2g}\right) = 0.19\left(\frac{11.94^2}{2 \times 9.81}\right) = \textbf{1.38 m of oil} \quad \textbf{Ans.} ☜$$

The pressure drop (ΔP) across the valve is given by,

$$\Delta P = H_L \times w_{oil}$$

$$= 1.38 \times 8829 = \textbf{12,194.65 N/m}^2 \text{ or } \textbf{0.122 bar} \quad \textbf{Ans.} ☜$$

REVIEW AND SUMMARY

- ✓ *In this chapter, the basics of hydraulics such as the concepts of force, pressure and head; concept and applications of Pascal's law; difference between laminar and turbulent flow; definition and significance of Reynolds number; and the concept and applications of Darcy's equation have been discussed, in detail.*
- ✓ *Pressure head,* $P = \rho g h$
- ✓ *If the pressure is measured with reference to the atmospheric pressure, then it is called* ***gauge pressure.*** *Any pressure measured above the absolute zero pressure is termed as* ***'absolute pressure'.***

  Absolute pressure = Gauge pressure + Atmospheric pressure

  Vacuum pressure = Atmospheric pressure – Absolute pressure
- ✓ *Work = Force × Distance moved*
- ✓ *Power = Work done/Time taken*
- ✓ *Energy is capacity to do work.*
- ✓ *Torque = Force × Moment arm = F × R*
- ✓ *Power transmitted by a shaft,* $P = \frac{2\pi NT}{60}$
- ✓ *Efficiency,* $\eta = \frac{\text{Output power}}{\text{Input power}}$
- ✓ ***Pascal's law :*** *The pressure applied to a confined fluid is transmitted undiminished in all directions.*

- ✓ *The two important applications of Pascal's law are : 1. Bramah's hydraulic press, and 2. Air-to-hydraulic pressure booster.*
- ✓ *In a hydraulic press, the output force is greater than the input force, but the output movement will be lesser than the input movement.*
- ✓ ***Reynolds number :*** $Re = \frac{\rho V D}{\mu} = \frac{V D}{\nu}$

  where the notations have usual meanings.
- ✓ *If Re < 2000, then the flow is laminar.*

  If Re > 4000, then the flow is turbulent.

  If 2000 < Re < 4000, then the flow is unpredictable.
- ✓ ***Flow rate or discharge :*** $Q = \frac{\text{Volume of liquid in m}^3}{\text{Time in sec}} = \frac{V}{t}$

  or $Q = \text{Area} \times \text{Velocity} = A \times V$
- ✓ ***Continuity equation :*** $Q = A_1 V_1 = A_2 V_2 = Q_2$
- ✓ *Total energy (or head) of a liquid in motion,* $E = z + \frac{V^2}{2g} + \frac{P}{w}$
- ✓ ***Bernoulli's equation :***

  $$z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w}$$
- ✓ ***Energy equation (Modified Bernoulli's equation) :***

  $$z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w} + H_L$$
- ✓ ***Darcy's equation*** *is used to calculate the head loss due friction in the pipes.*

  $$H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$
- ✓ ***Laminar friction factor :*** $f = \frac{64}{Re}$
- ✓ ***Hagen-Poiseuille equation :*** $H_L = \frac{64}{Re}\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$
- ✓ *Relative roughness* $= \frac{\varepsilon}{D}$
- ✓ ***Head loss in vales and fittings :*** $H_L = K\left(\frac{V^2}{2g}\right)$
- ✓ *At the end of the chapter, some illustrative examples are presented for better understanding of the basics.*

KEY TERMS ONE SHOULD REMEMBER

- **Force**
- **Pressure head**
- **Pressure**
  - **Atmospheric pressure**
  - **Gauge pressure**
  - **Absolute pressure**
  - **Vacuum pressure**
- **Work**
- **Power**
- **Energy**
- **Torque**
- **Efficiency**
- **Pascal's law**
- **Hydraulic press**
- **Hydraulic jack**
- **Air-to-hydraulic pressure booster**
- **Flow rate**
- **Discharge**
- **Laminar flow**
- **Turbulent flow**
- **Reynolds number**
- **Continuity equation**
- **Fluid energy in motion**
- **Bernoulli's equation**
- **Energy equation**
- **Modified Bernoulli's equation**
- **Energy losses in pipes**
- **Darcy's equation**
- **Friction factor**
- **Hagen-Poiseuille equation**
- **Relative roughness**
- **Moody diagram**
- **K-factor**

REVIEW QUESTIONS

Short Answer Type Questions

1. What is the difference between force and pressure ?
2. What do you mean by the term 'pressure head'.
3. Distinguish between gauge and absolute pressures. What is the relationship between them ?
4. Differentiate between power and energy.
5. State Pascal's law.
6. Name any two applications of Pascal's law.
7. What is the purpose of hydraulic press ?
8. What is the use of air-to-hydraulic pressure booster ?
9. Differentiate between laminar and turbulent flow.
10. What is Reynolds number ? Write its significance with reference to fluid power systems.
11. Name two causes of turbulence in fluid flow.
12. If the temperature increases so that the fluid viscosity decreases, would the Reynolds number increase, decrease, or remain the same ?
13. What is meant by flow rate ?
14. State the continuity equation.
15. What do you mean by the terms potential head, velocity head, and pressure head ?

16. Write down the Bernoulli's equation. Write its effect on the fluid flow in a hydraulic system.
17. What do you understand by modified Bernoulli's equation ?
18. List out the various energy losses when liquid flows through a pipe.
19. Give the Darcy's equation. What is the use of it ?
20. Write down the Hagen-Poiseuille equation.
21. Write a short note on the term friction factor.
22. Define the term relative roughness.
23. What is Moody diagram ? Write its use.
24. Give the expression to calculate the loss of head in the valves and fittings of a pipe.
25. What do you understand by the K factor of a valve or fitting ?
26. Name any two flow-measuring devices.
27. Name any two pressure-measuring devices.

Essay Answer Type Questions

1. (*a*) State and explain Pascal's law.
   (*b*) With neat sketches, explain the working of a hydraulic press and an air-to-hydraulic pressure booster.
2. (*a*) Explain the various loss of energy in flow through pipes.
   (*b*) Explain how you can determine the frictional losses in (*i*) laminar flow, and (*ii*) turbulent flow.
3. Write a short note on the following :
   (*a*) Laminar and turbulent flow.
   (*b*) Energy losses in valves and fittings.

Unit 2

Hydraulic System and Components

Chapter 5 : Pump : The Hydraulic Source

Chapter 6 : Hydraulic Actuators : The Transmitter

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Chapter 5

Pump - The Hydraulic Source

> *"The real problem is not whether machines think but whether men do."*
> ***–Joseph Snipp***

> *"Wisdom is the reward of listening... when you'd have preferred to talk."*
> ***–D.J. Kaufmann***

> *"Two things are infinite: the universe and human stupidity; and I'm not sure about the universe."*
> ***–Albert Einstein***

> *"I invent nothing. I rediscover."*
> ***–Auguste Rodin***

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Understand the principle and uses of the hydraulic pumps.

☑ Differentiate between positive displacement and non-positive displacement pumps.

☑ Describe and appreciate the principle, construction, operation, advantages, limitations, and applications of various types of gear, vane, and piston pumps.

☑ Distinguish between fixed displacement and variable displacement pumps.

☑ Compute the volumetric displacement and theoretical discharge of the various positive displacement pumps.

☑ Evaluate the pumps' performance by computing the various pump efficiencies.

☑ Analyse and compare the characteristic curves and the various performance factors of different pumps.

☑ Select the appropriate hydraulic pump for a specific application.

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CHAPTER 5

Pumps – The Source of Hydraulic Power

5.1. INTRODUCTION

As discussed in Section 1.7, any hydraulic system requires six basic components : reservoir, pump, electric motor (or prime mover), valves, actuator, and fluid-transfer piping. Though each of these components is very essential for proper functioning of the system, the pump is extremely important component to facilitate transfer of power and motion. In fact, the hydraulic pump is said to be the heart of the hydraulic system.

In this chapter, we shall discuss the construction and working of different types of pumps, their typical applications, selection, and performance.

5.1.1. What is a Hydraulic Pump ?

- ✓ ***Definition :*** *A hydraulic pump*[†] *is a device which converts mechanical energy into hydraulic energy.*
- ✓ The pump is used to impart motion to a liquid.[††] It provides the force required to transmit power and motion.
- ✓ The pump does not produce pressure. It produces only fluid flow.

5.2. PUMPING THEORY (PRINCIPLE OF PUMP)

Normally the powered electric motor converts the electrical energy into mechanical energy which is used to drive the shaft of the pump. The pump in turn coverts the mechanical energy into hydraulic energy by creating a partial vacuum at the inlet, which induces the atmospheric pressure to force the fluid through the inlet line. Then the internal design of the pump mechanically pushes the fluid to the outlet line.

5.2.1. How a Pump Works ?

The working principle of the pump can be better explained by referring to the simple piston pump as shown in Fig.5.1.

[†] In contrast, the devices used to convert hydraulic energy into mechanical energy are known as ***turbines or motors.***

[††] Instead of liquid, if gas is employed then other terms may be used. If the primary objective is to increase the pressure of the gas, the device is termed a ***compressor.*** On the other hand, a device used primarily for causing the movement of a gas is known as ***a fan or blower.***

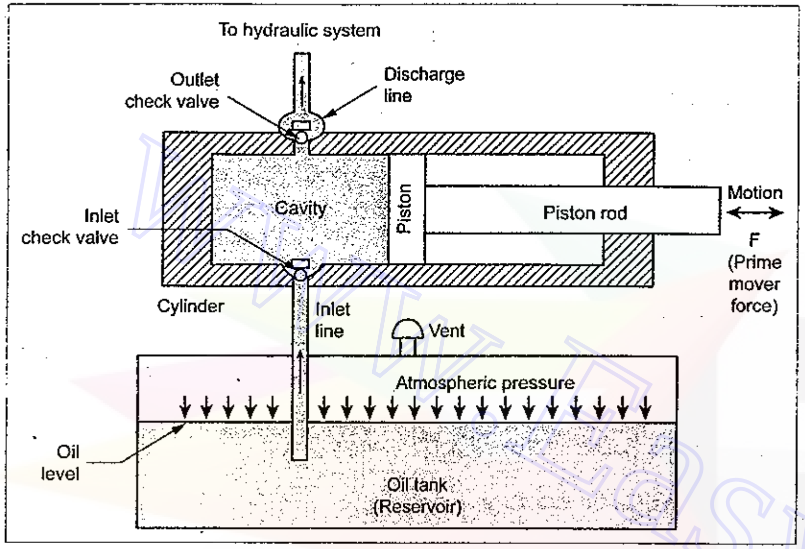


Fig. 5.1. Pumping action of a simple piston pump

As shown in Fig.5.1, the pump has the following two ball-check valves :

Inlet check valve : It is connected to the pump inlet to allow fluid to enter the pump.

Outlet check valve : It is connected to the pump outlet to allow fluid to leave the pump.

When the piston is pulled to the right, a partial vacuum is generated in pump cavity. The vacuum created in the cavity makes the outlet check valve to close the outlet line and allows the atmospheric pressure to push fluid from the reservoir into the pump via the inlet check valve.

When the piston is pushed to the left, the fluid movement forces the inlet check valve to close and open the outlet check valve. The quantity of fluid displaced by the piston is ejected out through the outlet line. Thus the pump produces flow of fluid.

5.2.2. Uses of Pump (Where Do You Need a Pump ?)

The two broad applications of pump are given below :

1. Pump is used to *transport liquid* as the case in pumps for the irrigation or pumps used in house. In this case, the outlet line is open to the atmosphere. There is no resistance to the fluid flow, so there will be no discharge pressure above atmosphere but there will be flow. These types of pumps will fall into positive displacement pumps (refer Section 5.3.1).
2. Pump is used to *develop pressure* in fluid-power systems. In fluid-power system, outlet line is not exposed to atmosphere (output line is blocked). Liquid is ideally an incompressible fluid, so the resistance to the fluid flow delivered at the outlet line is the pressure developed by the pump. The hydraulic power developed by pumps is converted back into mechanical energy by hydraulic actuators connected to the output line. Theoretically we have infinite resistance to flow. The pressure will therefore rise until some component breaks unless pressure relief is provided. That's why the pressure relief valve is used in fluid-power systems. When the pressure reaches the set value, the relief value will open to allow the flow back to the oil tank.

5.3. PUMP CLASSIFICATION

With reference to the fluid power applications, pumps can be broadly classified into : (*i*) Positive displacement pumps, and (*ii*) Non-positive displacement pumps. They are further classified into many types, as shown in Fig.5.2.

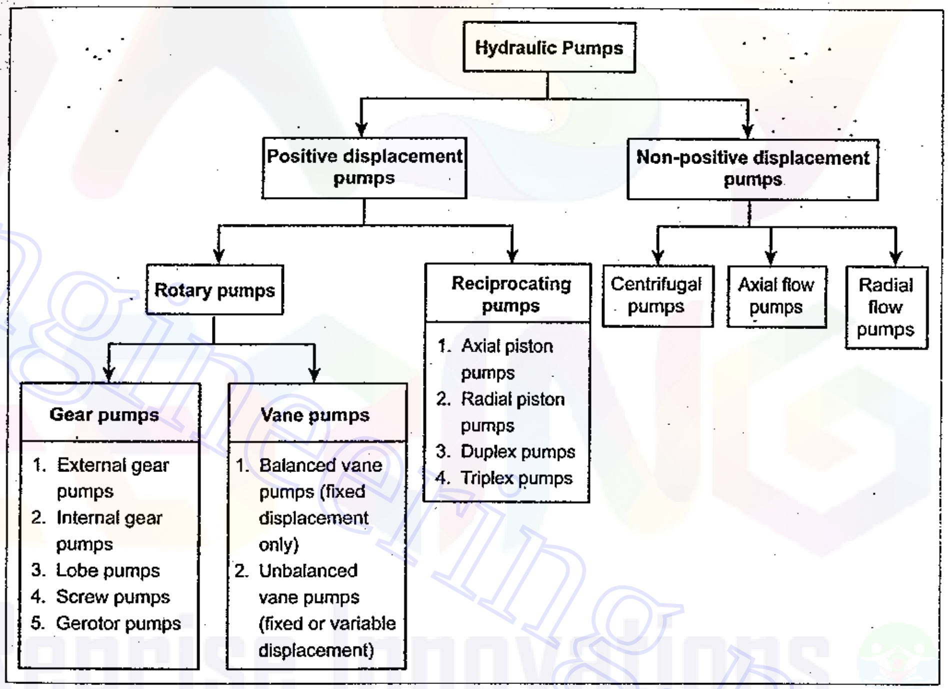


Fig. 5.2. Classification scheme of pumps

5.3.1. Positive (or Hydrostatic) Displacement Pumps

✓ As the name implies, the functioning of a positive-displacement pump derives from changes of the volume occupied by the fluid within the pump.

✓ Since the operation of the pumps depend only on mechanical and hydrostatic principles, these pumps are also called as ***hydrostatic displacement pumps.***

✓ Positive displacement pumps are primarily used where pressure development is the prime requirement. This type of pumps is capable of delivering high pressure fluid, so it is universally used in fluid power systems.

✓ These pumps discharge a fixed quantity of fluid into the hydraulic system per revolution of pump shaft rotation. Since the flow of fluid is guaranteed on every revolution of the shaft, this type of pump is named as *'positive displacement pump'*.

✓ ***Types :*** Positive displacement pumps can be further divided into :
1. Fixed displacement pumps, and 2. Variable displacement pumps.

1. Fixed Displacement Pumps : In fixed displacement pumps, the amount of fluid ejected per revolution (displacement) is constant and it cannot be varied.

2. Variable Displacement Pumps : In variable displacement pumps, the displacement can be varied by changing the physical relationships of various pump elements. This change in pump displacement produces a change in output of fluid flow even though pump speed remains constant.

✓ ***Examples :*** Some of the positive displacement pumps are gear, vane, piston, and screw pumps.

✓ ***Advantages of Positive Displacement Pumps***

The major advantages of the positive displacement pumps are as follows :

1. Positive displacement pumps can operate at very high pressure (upto 700 bar).
2. They are small and compact in size.
3. They have very high power-to-weight ratio.
4. They achieve high volumetric efficiency.[†]
5. The efficiency will not vary much for the wide range of pressure.
6. They have greater flexibility of performance (as they can operate over a wide range of pressure requirement and speed ranges).

✓ ***Applications :*** These pumps are widely used in all fluid power applications.

5.3.2. Non-Positive (or Hydrodynamic) Displacement Pumps

✓ In non-positive displacement pumps, the fluid flow is achieved using the inertia of the fluid in motion.

✓ These pumps are suitable for low-pressure (upto 40 bar), high-volume flow applications.

✓ Since these pumps cannot withstand high pressures, they are used only for transporting fluid from one place to another. For the same reason, they are not preferred in the fluid power industries.

[†] For more details on volumetric efficiency refer Sections 5.5.4 and 5.17.1.

✓ ***Examples :*** Some examples of such pumps are centrifugal (impeller) pumps and axial (propeller) pumps.

✓ In these pumps, the clearance between the rotating and stationary elements is large and hence their output flow rate is low.[†] The pump flow rate depends not only on the rotational speed but also on the resistance of the external system. As the external resistance increases, the flow rate decreases. ***Since the output flow varies significantly with the external circuit resistance, these pumps are not used in hydraulic systems.***

✓ ***Advantages and Disadvantages of Non-displacement Pumps***

Table 5.1 presents the merits and demerits of employing the non-displacement pumps.

Table 5.1. Advantages and disadvantages of non-displacement pumps

Advantages	Disadvantages
✓ Non-displacement pumps have fewer moving parts. ✓ Their initial and maintenance costs are comparatively less. ✓ They provide smooth continuous flow. ✓ They are suitable for handling almost any type of fluid (including sludges, slurries, *etc.*) ✓ They are highly reliable. ✓ They are simple in operation.	✓ These pumps are not self-priming and hence they must be positioned below the fluid level. ✓ The output flow rate varies with the external circuit resistance. ✓ Volumetric efficiency is very low.

✓ ***Applications :*** These pumps are suitable only in fluid transport systems for transporting fluid from one location to another.

5.3.3. Types of Positive Displacement Pumps

Now it is evident that from our subject point of view we are concerned more about positive displacement pumps. Now we shall discuss the construction and working of the following positive displacement pumps, in the following sections.

1. Gear pumps
   - (*a*) External gear pumps, (*b*) Internal gear pumps,
   - (*c*) Lobe pumps, and (*d*) Screw pumps.
2. Vane pumps
   - (*a*) Unbalanced vane pumps, and (*b*) Balanced vane pumps.
3. Piston pumps
   - (*a*) Axial design piston pumps, and (*b*) Radial design piston pumps.

[†] To have better understanding of a non-displacement pump (*i.e.*, centrifugal pump), refer Article 4, Appendix I.

5.4. GEAR PUMPS

5.4.1. Introduction

- ✓ Gear pumps are the simplest and the most widely used pumps for hydraulic systems.
- ✓ Gear pump is the most robust positive displacement pump, having only two moving parts.
- ✓ All the gear pumps are invariably ***fixed displacement type.*** That means, the amount of fluid pumped by these pumps is theoretically constant for each revolution of the driver shaft.

5.4.2. Principle of Working

The basic principle of this type of pump is that as pair of gears being driven by an external means (electric motor, engine, *etc.*), a partial vacuum is created in the pump. The gear motion generates a suction at the inlet, which causes fluid to be drawn into the pump housing. The fluid is drawn through the pump and is displaced as the teeth mesh on the outlet side.

5.5. EXTERNAL GEAR PUMPS

5.5.1. Construction

External gear pumps have two mating gears (driver and follower) that are turned in a closely fitted casing, as shown in Fig.5.3. Each gear is mounted on a shaft which is supported on bearings in the end covers. In these, the driver shaft is coupled to the prime mover (electric motor, gasoline engine, *etc.*). Two parts—inlet and delivery parts—are provided directly on the opposite sides of the mesh point of the gears. The larger and straight ports are preferred for better performance. The driving shaft is usually connected to the upper gear of the pump. The rotation of the driver gear causes the follower gear to turn.

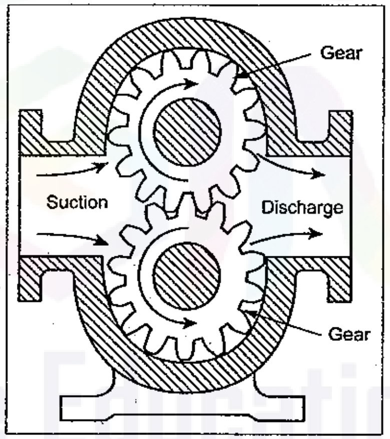


Fig. 5.3. External gear pump

5.5.2. Operation

The self-explanatory Fig.5.4 explains the operation of the external gear pump in steps.

When the pump starts rotating, the rotation of gears forces air out of the casing and into the discharge pipe [Fig.5.4(*a*)]. This removal of air from the pump casing produces a partial vacuum on the suction side of the pump. Fluid from an external reservoir is forced by the atmospheric pressure into the pump inlet. Here the fluid is trapped between the teeth of the upper and lower gears and the pump casing [Fig.5.4(*b*)]. Continued rotation of the gears forces the fluid out of the pump discharge [Fig.5.4(*c*)].

A vacuum is formed in the cavity between the teeth as they un-mesh, causing more fluid to be drawn into the pump. Pressure rise in the pump is produced by the squeezing action on the fluid as it is expelled from between the meshing gear teeth and the casing.

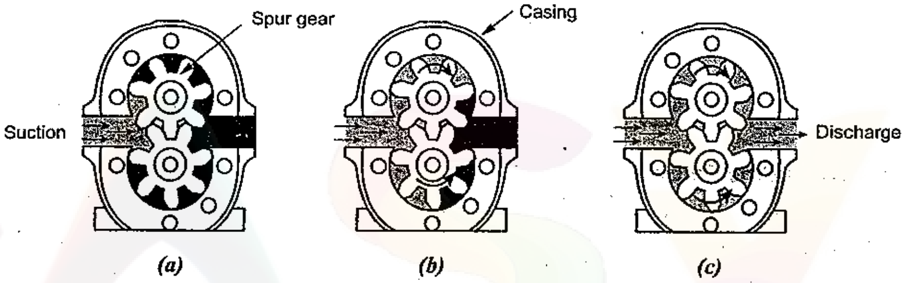


Fig. 5.4. Operation of external gear pumps : (a) Vacuum draws fluid into pump. (b) Teeth carry fluid through pump. (c) Fluid is discharged under pressure

5.5.3. Analysis of Volumetric Displacement and Theoretical Flow Rate

The volumetric displacement and theoretical flow rate of a gear pump can be determined as follows :

Let D_i = Inside diameter of gear teeth in m,

D_o = Outside diameter of gear teeth in m,

L = Width of gear teeth in m,

N = Speed of pump in rpm,

V_D = Volumetric displacement of the pump in m^3/rev, and

Q_T = Theoretical pump flow rate in m^3/sec.

If addendum and dedendum of a gear is known, then inside diameter of gear teeth can be calculated by

$$D_i = D_o - 2\,(\text{Addendum} + \text{Dedendum})$$

The volumetric displacement, from the geometry of the gear teeth, is given by,

$$\boxed{V_D = \frac{\pi}{4}\,(D_o^2 - D_i^2)\,L} \qquad \ldots (5.1)$$

Then the theoretical flow rate can be calculated as

$$\boxed{Q_T = \frac{V_D \times N}{60}} \qquad \ldots (5.2)$$

From equation (5.2), it is evident that the pump flow rate depends on :

(*i*) Size of the gear, and (*ii*) Speed of the pump.

Note If the gear is specified by its module and number of teeth, then the theoretical discharge can be found by using the following empirical relation :

$$\boxed{Q_T = 2\pi L m^2 N \left[z + \left(1 + \frac{\pi^2 \cos \alpha}{12} \right) \right] \text{ m}^3/\text{min}} \quad \ldots (5.3)$$

where
L = Width of gear teeth in m,
m = Module of gear in m,
N = Pump speed in rpm, and
z = Number of gear teeth.

5.5.4. Volumetric Efficiency

Obviously there will be a small radial clearance between the gear teeth and the casing so as to achieve the gears rotation. As a result, some of the fluid may leak inside the system without discharging at the outlet port. This internal leakage, also known as *'pump slippage'*, results in lesser flow rate (Q_A) than the theoretical flow rate (Q_T). This is represented by the volumetric efficiency.

$$\therefore \quad \boxed{\text{Volumetric efficiency, } \eta_{vol} = \frac{Q_A}{Q_T} \times 100} \quad \ldots (5.4)$$

where Q_A and Q_T are actual and theoretical flow rate of the pump respectively.

Since the internal leakage increases with the increase in discharge pressure, the volumetric efficiency will be lower for the high discharge pressure.

5.5.5. Advantages and Disadvantages of External Gear Pumps

Table 5.2 presents the merits and demerits of using the external gear pumps.

Table 5.2. Advantages and disadvantages of external gear pumps

Advantages	Disadvantages
✓ These pumps are self-priming. ✓ They give constant delivery for a set rotor speed, uniform discharge with negligible pulsations, and do no require check valves. ✓ If necessary, these pumps can pump in either direction (by changing the direction of the gear rotation). ✓ They have small space requirements. ✓ They are light in weight. ✓ They can handle liquids containing vapours and gases. ✓ Volumetric efficiency is high.	✓ The liquid to be pumped must be comparatively clean. ✓ The pump cannot be operated against a closed discharge without damage. Hence relief valves are required. ✓ Variable-speed drives are required to provide changes in pumping rate. ✓ These pumps depend on the liquid pumped to lubricate the internal moving parts and can be damaged if run dry.

5.5.6. Ranges of External Gear Pumps

- ✓ *The gears in the gear pumps can be of spur gear, helical gear or herringbone gear.*
- ✓ External gear pumps containing spur gears are normally low-capacity (about 15 Lps) pumps. For higher capacities the noise level and thrust on the bearings become too great.
- ✓ The helical and herringbone gear pumps are used in higher-capacity pumps. Also both types of pumps can bundle higher-viscosity liquids.
- ✓ Since the helical gear configuration develops the end thrusts, the pressure applications of helical gear pumps is limited to below 15 bar.
- ✓ To overcome the drawbacks of both spur and helical gear pumps, herringbone gear pumps are used. The herringbone gear pumps are available with capacities upto 325 Lps and for pressures upto 200 bar.

5.6. INTERNAL GEAR PUMP

5.6.1. Introduction

The operation of internal gear pumps is very much similar to external gear pumps, but they are very efficient and produce less noise. The gears rotate in the same direction, with the inner gear rotating at a higher speed. Generally the internal gear pumps are used for low output applications at pressures below 70 bar. This pump is also known as ***crescent seal pumps.***

5.6.2. Construction

Internal gear pump consists of an internal spur gear, a outside ring gear, a crescent shaped spacer, and an external housing, as shown in Fig.5.5. The internal spur gear drives the outside ring gear which is set off-center (*i.e.*, both gears are eccentric to each other). The inner and outer gears are separated by a crescent shaped spacer, which is a stationary part of the housing around which oil is carried. The inlet and outlet ports are located in the end plates between where the gear teeth mesh and un-mesh at the two ends of the crescent shaped spacer.

5.6.3. Operation

The operation of the internal gear pumps is similar to external gear pumps. Oil is transferred from the inlet to the outlet port. The internal gear drives the external gear and affects a fluid tight seal at the place where the teeth start meshing. Rotation causes the teeth to un-mesh near the inlet port, the cavity volume increases and the suction occurs. The oil is trapped between the internal and external gear teeth on both sides of the crescent shaped spacer and is carried from the inlet to the outlet cavity of the pump, as shown in Fig.5.5. Meshing of the gear teeth reduces the volume in the high pressure cavity near the outlet port and exits from the outlet port.

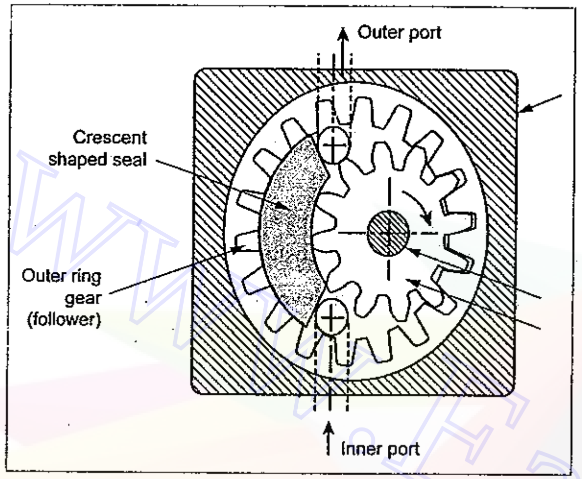


Fig. 5.5. Operation of an internal gear pump

5.6.4. Advantages and Disadvantages of Internal Gear Pumps

- ✓ The advantages and disadvantages of internal gear pumps are the same as listed in Table 5.2 for external gear pumps.
- ✓ Unlike in external gear pumps, the gears in an internal gear pump rotate in the same direction.
- ✓ The slow relative rotation and the rolling contact between the gears reduce friction, wear, and turbulence.
- ✓ These pumps also permit pumping of liquids that are more shear sensitive.

5.6.5. Ranges

Internal gear pumps are available with capacities upto 70 Lps and the discharge pressures are limited to 7 bars.

5.7. LOBE PUMP

5.7.1. Introduction

In this pump, the gear wheels are replaced by propellers of two, three or four lobes.[†] That's why it is named as a lobe pump. This pump is quieter in operation than other types of gear pumps. This type of pump is used for pumping liquid, gas, and air with low pressures and higher flow rate.

5.7.2. Construction and Operation

The principle of a three-lobe pump is illustrated in Fig.5.6. The lobe pump consists of two lobes placed in housing.

[†] Lobe means a part similar to the lower soft pendulous part of the outer ear.

The operation of this pump is similar to that of the external gear pump. But unlike the external gear pump, both lobes are driven externally and they do not have actual contact with other. The lobes rotate, creating two chambers between the lobes and the wall of the pump chamber. The lobes are rotated, one being directly driven by the source of power, the other through timing gears.

As the lobes turn, fluid is held between each lobe and the wall of the pump chamber and carried around from suction to discharge. Since the surfaces of the lobes are smooth and curvy, they do not actually contact each other. Thus these pumps do not make noise. Also the volumetric displacement is generally greater than that for other types of gear pumps.

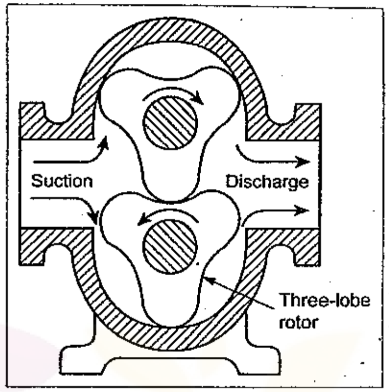


Fig. 5.6. Lobe pump

5.7.3. Advantages and Disadvantages of Lobe Pumps

The advantages and disadvantages of lobe pumps are the same as for external gear pumps, with the following exceptions :

- ✓ The output from lobe pumps pulsates more than that from external gear pumps. Since the lobes operate as gears, the greater the number of lobes, the less the pulsation.
- ✓ Lobe pumps tend to wear less than external gear pumps.

5.7.4. Ranges

Lobe pumps are available with capacities upto 140 Lps and the discharge pressures upto 30 bar.

5.8. GEROTOR PUMP

5.8.1. Introduction

In principle, the gerotor pump operates very much similar to internal gear pumps. In fact, the gerotor pump is an another version of internal gear pump.

5.8.2. Construction

The gerotor pump consists of inner gerotor, outer gerotor and a housing, as shown in Fig.5.7. In these, the inner gerotor is the driver and the outer gerotor is the follower. To simplify the design, only one shaft is involved. Also the outer gerotor has one more tooth than the inner gerotor. Both gerotors rotate in the same direction. But gerotors have two different centre of rotation. If the number of teeth on the inner and outer gerotors are 5 and 6 respectively, then for the one revolution of inner gerotor, the outer gerotor makes only 5/6 or 0.83 revolution. In order to avoid excessive internal leakage, gerotors must be made to high precision.

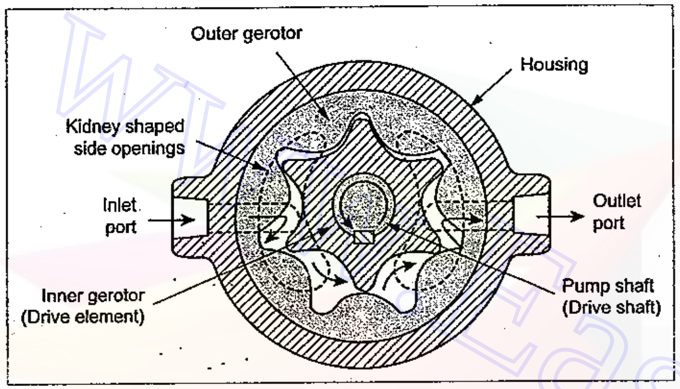


Fig. 5.7. Gerotor pump

5.8.3. Operation

The power-driven inner gerotor draws the outer gerotor around and they mesh together. Each tooth of the gerotor is always in sliding contact with the surface of the outer element. This sliding contact provides the sealing effect.

As the teeth disengage, the space between them increases. This creates a partial vacuum and hence the oil is sucked into the chamber through the suction port. When the space or chamber reaches its maximum volume, the suction stops. As the space diminishes with the meshing of the teeth, it forces the oil to discharge from the pump through the outlet port.

5.9. SCREW PUMP

5.9.1. Introduction

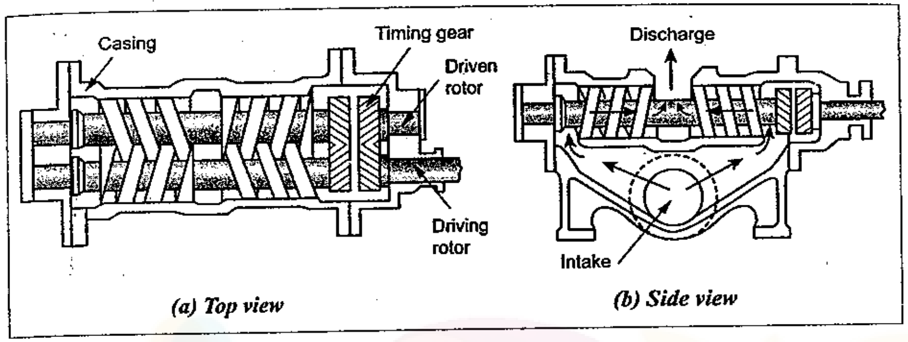
Screw pumps are one of the most reliable pumps for hydraulic applications. Especially these pumps are employed where quiet operation is essential.

5.9.2. Construction

The screw pump is an axial flow, positive displacement type gear pump. A two-rotor screw pump with helical gears and its cross-sectional view are shown in Figs.5.8(a) and (b).

These pumps have (two or more) meshing screws to develop the required pressure. These screws mesh to form a fluid tight seal between the screw recess and housing wall. The only moving parts in these pumps are screws.

In the two-rotor screw pump, the driving screws and driven screws are connected by means of timing gears. The timing gears are provided to maintain a running clearance between the two meshing screws.



(a) Top view *(b) Side view*

Fig. 5.8. Screw pump

5.9.3. Operation

The liquid is introduced at the two ends and discharged at the centre, as shown in Fig.5.8(b). The pumping action comes from the 'sealed chamber'. The sealed chamber formed by the contact of the two gears at the intersection of their addenda and by the small clearance between the screws and the pump housing. This working is similar to a nut moving along a threaded rod when the rod is rotated. In these pumps, it should be noted that the liquid does not rotate but moves linearly. Thus the liquid moves forward along the axis with the rotation of the screw and is discharged to the outlet port.

5.9.4. Advantages of Screw Pumps

Some of the noteworthy merits and demerits of screw pumps are presented in Table 5.3.

Table 5.3. Advantages and disadvantages of screw pumps

Advantages	Disadvantages
✓ Self-priming.	✓ These pumps are bulky and heavy.
✓ Most reliable.	✓ It is difficult to manufacture the screw profile to maintain close tolerance.
✓ Give uniform pressure with negligible pulsations.	✓ Pressure rating of the screw pump is viscosity dependent. So pumping of higher viscosity oil may decrease the pump efficiency.
✓ Very quiet, because of rolling action of the screw spindles.	✓ Overall volumetric and mechanical efficiency is relatively low.
✓ Do not require check valves.	
✓ Produce relatively long wear on moving parts.	
✓ Can handle liquids containing vapours and gases.	
✓ Exceptionally long life.	

5.9.5. Range

Screw pumps are available with capacities upto 190 Lps and the discharge pressures upto 250 bar. Also these pumps can operate at very high speeds (upto 3500 rpm).

Note From the above discussion, the following three advantages of gear-type pumps are evident.

1. Gear type pumps have fewer moving parts.
2. They exhibit simplicity in design and construction.
3. They are expensive.

5.10. VANE PUMPS

5.10.1. Introduction

The major problem in gear pumps is that the significant amount of leakage occurs between the small gaps of teeth, and also between teeth and pump housing. The vane pumps reduce this leakage by using spring-or hydraulic-loaded vanes.

5.10.2. Types of Vane Pumps

The two important types of vane pumps are :

1. Unbalanced vane pumps, and
   (*a*) Fixed-displacement unbalanced pumps, and
   (*b*) Variable-displacement unbalanced pumps.
2. Balanced vane pumps.

5.11. UNBALANCED VANE PUMP

5.11.1. Construction and Operation

Fig.5.9 illustrates a typical unbalanced sliding-vane pump.

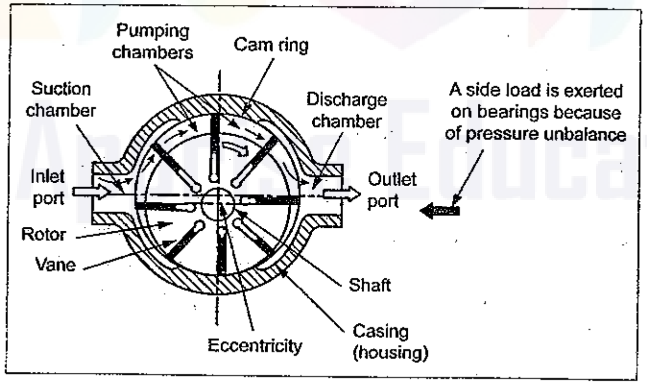


Fig. 5.9. Unbalanced vane pump

In this pump, the rotor is mounted off-center. At regular intervals around the curved surface of the rotor are rectangular vanes that are free to move in a radial slot. As the rotor revolves, the vanes are thrown outwards by centrifugal force to form a seal against the fixed casing. The eccentricity of the revolving rotor produces a partial vacuum at the suction side of the pump, causing an inflow of liquid. This is carried to other side of the pump in the space between the rotor and the fixed casing.

Generally, pumping rates of these rotary pumps are varied by changing the speed of the rotor. However in unbalanced vane pumps, the pumping rate can also be varied by changing the degree of eccentricity of the rotor, since this determines the amount of liquid carried through per cycle.

5.11.2. Fixed-Displacement Unbalanced Vane Pumps

In the fixed displacement pump, the rotor-housing eccentricity is constant. Hence the displacement volume is fixed. A constant volume of fluid is discharged during each revolution of the rotor.

5.11.3. Variable-Displacement Unbalanced Vane Pumps

Variable displacement can be provided if the housing can be moved with respect to the rotor. This movement changes the eccentricity and hence the displacement. Usually a hand wheel or pressure compensator can be used to move the cam ring to change the eccentricity.

5.11.4. Analysis of Volumetric Displacement

With reference to the Fig.5.9, the volumetric displacement of the vane pump can be determined by using the following relation :

$$\boxed{\text{Volumetric displacement, } V_D = \frac{\pi}{2}(D_C + D_R)\, e\, L} \quad \ldots (5.5)$$

where V_D = Volumetric displacement in m^3,

D_C = Diameter of cam ring in m,

D_R = Diameter of rotor in m,

L = Width of rotor in m, and

e = Eccentricity in m $= \dfrac{(D_C - D_R)}{2}$

If N = Rotor speed in rpm, then the theoretical flow rate can be given by,

$$\boxed{Q_T = V_D \times N} \quad \ldots (5.6)$$

Note 1. This pump is referred as unbalanced pump because all of the pumping action takes place on one side of the rotor. This causes a side load to the rotor, as shown in Fig.5.9.

2. In addition to sliding vanes, rolling vanes and swinging vanes are also available in unbalanced vane pumps. Each of these variations is hydrostatically unbalanced. This unbalance causes high bearing loads and generally limits the application of unbalanced vane pumps to operating pressures less than about 100 bar.

5.12. BALANCED VANE PUMP

5.12.1. Construction and Operation

Unlike in unbalanced vane pump, the balanced vane pump has two intake and two outlet ports which are diametrically opposite to each other. Also a balanced vane pump has an elliptical housing instead of a circular cam ring. This configuration creates two diametrically-opposed volumes. The two high-pressure zones balance the forces on the rotor shaft and hence a complete hydraulic balance is achieved.

Fig.5.10 illustrates the operation of a balanced vane pump. Except the above said differences, the construction and basic working principle are similar to the unbalanced vane pumps.

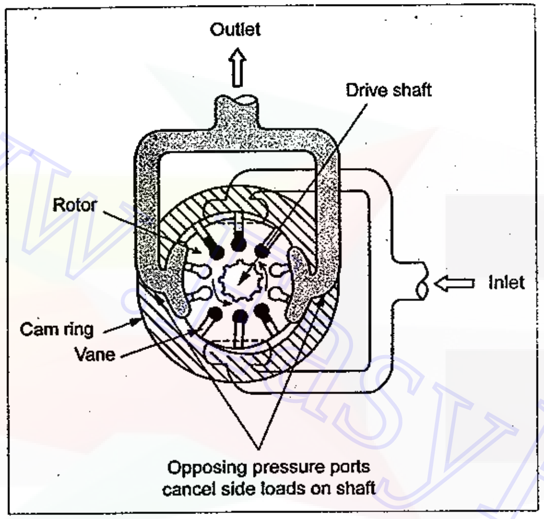


Fig. 5.10. Balanced vane pump operation

5.12.2. Advantages and Disadvantages of Balanced Vane Pumps (Over Unbalanced Vane Pumps)

Table 5.4 presents the merits and demerits of balanced vane pumps over unbalanced vane pumps.

Table 5.4. Advantages and disadvantages of balanced vane pumps

Advantages	Disadvantages
✓ The balanced design of pump eliminates the bearing side loads and thus permits higher operating pressures.	✓ Balanced vane pumps are necessarily fixed displacement machines. Therefore the displacement of pumps cannot be varied.
✓ The balanced vane pumps have much improved service lives over simpler unbalanced vane pumps.	✓ Due to its symmetrical construction, balanced vane pumps are difficult to design as variable displacement pumps.

5.12.3. Advantages and Disadvantages of Vane Pumps

Table 5.5 summarises the merits and demerits of employing vane pumps.

Table 5.5. Advantages and disadvantages of vane pumps

Advantages	Disadvantages
✓ Vane pumps are self-priming, robust, and give constant delivery for a set rotor speed. ✓ They produce uniform discharge with negligible pulsations. ✓ Their vanes are self-compensating for wear and also vanes can be easily replaced. ✓ These pumps do not require check valves. ✓ They can pump in either direction. ✓ They require little space. ✓ They are light in weight. ✓ They can handle liquids containing vapours and gases. ✓ Volumetric and overall efficiencies are relatively high. ✓ Only small changes in capacity occur with variations in viscosity and discharge pressure.	✓ Vane pumps cannot be operated against a closed discharge without damage to the pump. Hence relief valves are required. ✓ They cannot handle abrasive liquids. ✓ They require seals. ✓ Foreign bodies can damage the pump.

5.12.4. Ranges of Vane Pumps

Vane pumps are available with capacities upto 125 Lps and the discharge pressures upto 175 bar. Also these pumps can operate at speeds upto 2000 rpm.

5.13. PISTON PUMPS

5.13.1. Introduction

✓ In piston pumps, the pumping action is affected by a piston that moves in a reciprocating cycle through a cylinder. The basic operation of piston pumps are very similar to that of the reciprocating engines.

✓ ***Classification :*** Piston pumps can be classified by the motion of the piston relative to their drive shaft as :

1. Axial piston pumps, and
   (*a*) Bent axis type, and (*b*) Swash plate type.
2. Radial piston pumps.

✓ In axial piston pumps, a number of pistons and cylinders are located in a parallel position with respect to the drive shaft, while in the radial type they are arranged radially around the rotor hub.

5.14. AXIAL PISTON PUMP

5.14.1. Introduction

In the axial piston pump, rotary shaft motion is converted to axial reciprocating motion which drives the piston. Most axial-piston pumps are multi-piston designs and utilize check valves or port plates to direct liquid flow from inlet to discharge. Output can be controlled by manual, mechanical, or pressure compensated controls.

5.14.2. In-Line Axial Piston Pump

An axial piston pump, in which the pistons are in line with the axis of the drive shaft, is illustrated in Fig.5.11.

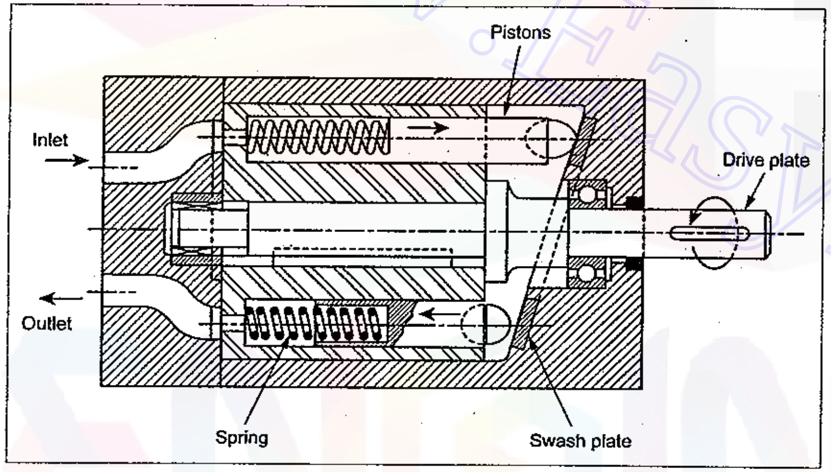


Fig. 5.11. In-line axial piston pump

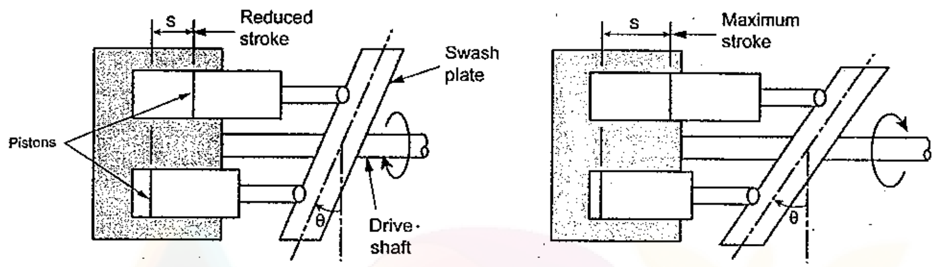
As shown in Fig.5.11, the rotary drive motion is converted to reciprocating, axial piston motion by means of the swash plate (also known as thrust cam or wobble plate), mounted on the drive shaft. Thus the rotation of the swash plate produces in-and-out motion of the pistons in their cylinders and hence the fluid is discharged.

5.14.2.1. Fixed-Displacement In-Line Axial Pump

The axial pump illustrated in Fig.5.11 is a constant-displacement piston pump. That means constant volume of oil is discharged for a set rotor speed. In these, pistons are stroked by a fixed angle plate.

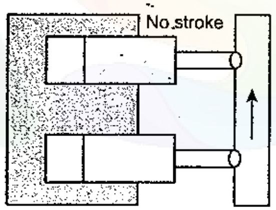
5.14.2.2. Variable-Displacement In-Line Axial Pump (Swash Plate Design)

This type of pump can also be designed to have variable displacement capability. This can be achieved by altering the angle of the swash plate. Because in the swash plate axial pump, the angle of tilt of the swash plate determines the piston stroke and hence the pump displacement. This is schematically illustrated in Fig.5.12.



(a) Decreased swash plate angle (partial displacement)

(b) Maximum swash plate angle (Maximum displacement)



(c) Zero swash plate angle (no displacement)

Fig. 5.12. Variation in pump displacement with swash plate angle

As could be seen from Fig.5.12, the increase in the swash plate angle (θ) will increase the piston stroke and hence the fluid displacement. When the swash plate is vertical (*i.e.*, angle is zero), then the displacement will be zero. Even one can reverse the flow direction by changing the angle of swash plate. However, the maximum swash plate angle is generally limited to 17½° , due to various design considerations.

5.14.3. Bent Axis Type Axial Piston Pump

5.14.3.1. Construction

A typical 3D bent axis type axial piston pump is illustrated in Fig.5.13. The simplified line sketch of the same is shown in Fig.5.14.

This type of pump contains a cylinder block rotating with the drive shaft. As shown in Fig.5.13, the centerline of the cylinder block is set at an offset angle relative to the centerline of the drive shaft. The cylinder block has a number of pistons and cylinders arranged along a circle. The ball and socket joints connect the piston rods with the drive shaft flange. When the distance between the drive shaft flange and cylinder block changes, the pistons move in and out of the cylinder. In order to provide alignment and positive drive, a universal link is used to connect the block to the drive shaft.

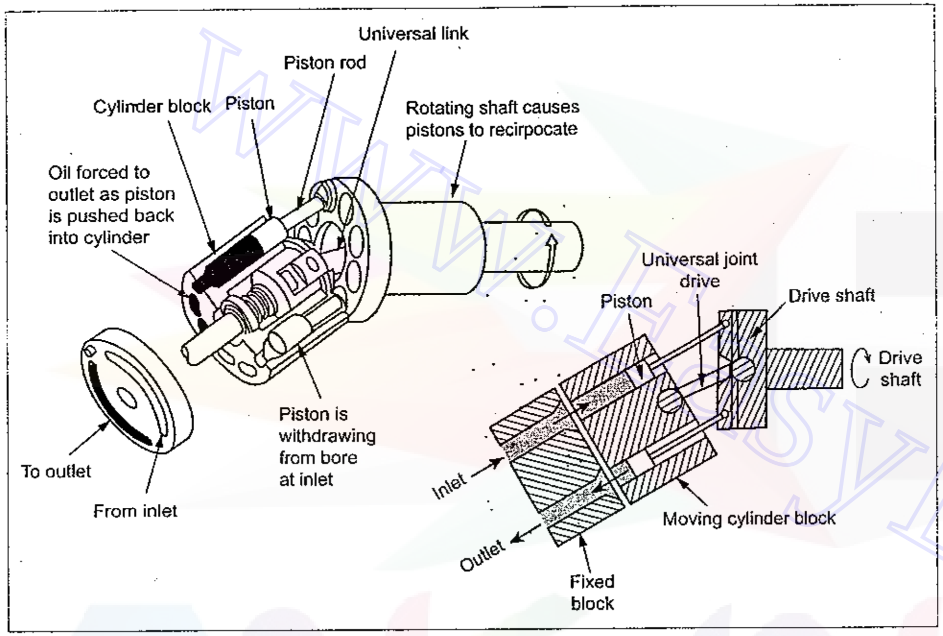


Fig. 5.13. Bent axis type axial piston pump

Fig. 5.14. Bent axis pump

5.14.3.2. Operation

When the piston carrying body turns, the exit passages in the cylinder bores move along the control slots of a firmly positioned control plate and are thus connected alternatively to the suction or discharge pipelines.

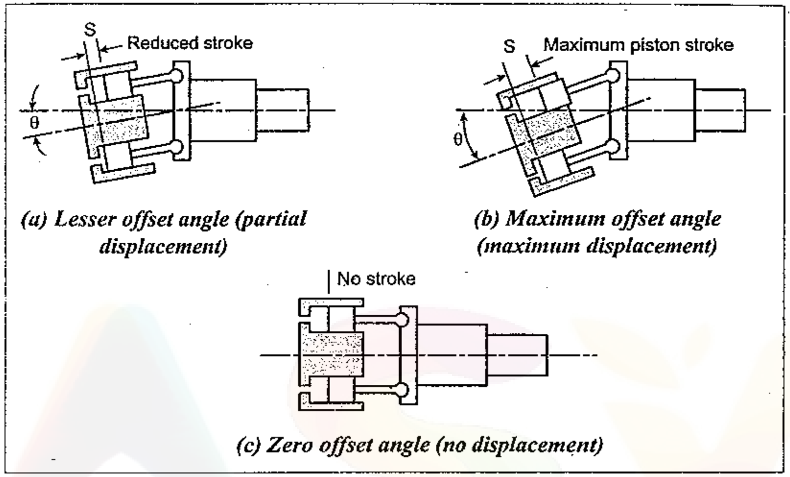
5.14.3.3. Fixed-Displacement Bent Axis Piston Pump

In fixed displacement pumps, the pumps are mounted in a fixed casing so that swing (or offset) angle cannot be adjusted. So the fixed displacement of the piston and hence the constant discharge of fluid are achieved.

5.14.3.4. Variable-Displacement Bent Axis Piston Pump

In variable-displacement pumps, the swing (or offset) angle can be varied. Because the volumetric displacement of the pump varies with the offset angle. The variation in pump displacement with respect to offset angle is schematically illustrated in Fig.5.15.

As could be seen from Fig.5.15, the increase in the offset angle (θ) will increase the piston stroke and hence the fluid displacement. When the offset angle is zero, then the displacement will be zero. However, for practical reasons, θ is to be varied from 0° to a maximum of about 30°.



(a) Lesser offset angle (partial displacement)

(b) Maximum offset angle (maximum displacement)

(c) Zero offset angle (no displacement)

Fig. 5.15. Variation in pump displacement with offset angle

5.14.4. Volumetric Displacement and Theoretical Flow Rate of an Axial Piston Pump

For any axial piston pump, the volumetric displacement and theoretical flow rate can be determined as follows :

Let θ = Offset angle in degrees,

S = Piston stroke in m,

D = Piston circle diameter in m,

d = Diameter of piston in m,

A = Cross-sectional area of the piston in m² $= \frac{\pi}{4} d^2$,

Y = Number of pistons, and

N = Rotor speed in rpm.

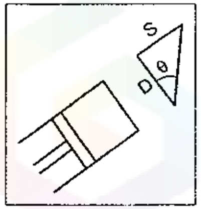


Fig. 5.16.

From the geometry of a piston (Fig.5.16), we get

$$\tan\theta = \frac{S}{D}$$

$$\text{or} \quad S = D\tan\theta \qquad \ldots (1)$$

We also know that,

Total displacement volume = (Displacement volume/Piston) × Number of pistons

$$\therefore \quad V_D = (\text{Area} \times \text{Stroke}) \times Y = ASY \qquad \ldots (2)$$

Substituting equation (1) in (2), we get

$$\boxed{V_D = YAD\tan\theta} \qquad \ldots (5.7)$$

Then the theoretical flow rate is given by,

$$\boxed{Q_T = YAND\tan\theta} \qquad \ldots (5.8)$$

5.15. RADIAL PISTON PUMP

5.15.1. Construction and Operation

The radial piston pump has a number of radial pistons (in similar fashion to the spokes of a wheel) in a cylinder block which revolves around a stationary eccentric cam. In these pumps, the pistons move perpendicularly to the shaft centerline. As the cylinder block rotates, the eccentricity of the cam causes an in-and-out or pumping motion of the pistons. This working principle is illustrated in Fig.5.17.

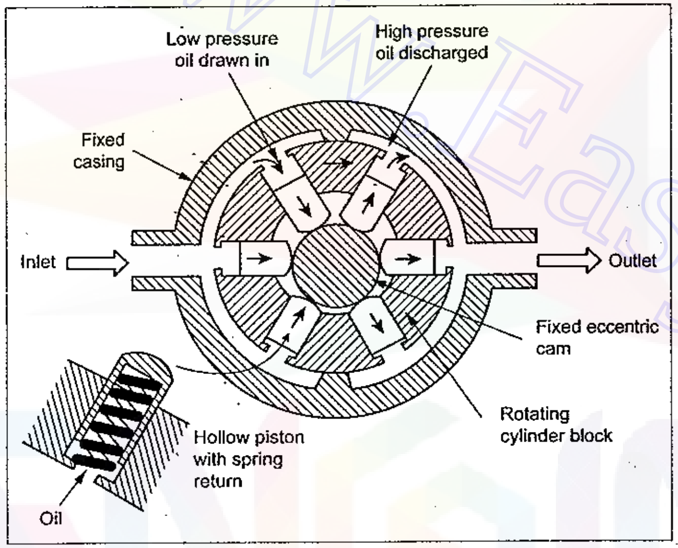

Low pressure oil drawn in
High pressure oil discharged
Fixed casing
Inlet
Outlet
Fixed eccentric cam
Rotating cylinder block
Hollow piston with spring return
Oil

Fig. 5.17. Radial piston pump

As could be seen from Fig.5.17, the fluid inflow and outflow at each piston is controlled through revolving ports. During the downstroke, each piston is connected to the fluid inlet and hence the fluid is drawn inside the cylinders. During the upward stroke, each piston is connected to the fluid outlet and hence fluid is discharged outside the pump.

5.15.2. Theoretical Flow Rate of a Radial Piston Pump

The theoretical discharge of a radial piston pump can be calculated by using the following relation :

$$\boxed{Q_T \;=\; 0.5\, e\, Y\, \pi\, d^2 N \quad \text{m}^3/\text{min}} \qquad \ldots (5.9)$$

where e = Eccentricity in m,

Y = Number of pistons,

d = Diameter of piston in m, and

N = Rotor speed in rpm.

5.15.3. Advantages and Disadvantages of Piston Pumps

Table 5.6 presents the merits and demerits of employing piston pumps.

Table 5.6. Advantages and disadvantages of piston pumps

Advantages	Disadvantages
✓ Piston pumps are capable of delivering high operating pressures. ✓ They can handle oils in a wide viscosity range. ✓ They can handle liquids containing vapours and gases. ✓ They can provide a variable delivery of liquid. ✓ They are self-priming. ✓ They are quite in operation. ✓ They have exceptionally long life.	✓ They tend to be heavy and bulky. ✓ They have a pulsating discharge. ✓ Power pumps cannot be operated against a closed discharge. Hence relief valves are required. ✓ Most types require inlet and discharge valves.

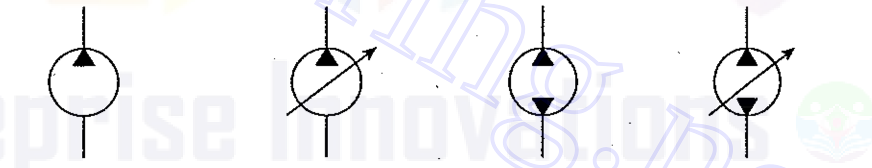
5.15.4. Ranges

Piston pumps are available with capacities from 1.25 Lps to 1250 Lps and the discharge pressures from 70 bar to 1400 bar. In addition, these pumps can operate at speeds over 2000 rpm.

Note Piston pumps can also be classified into simplex, duplex, and triplex pumps. ***A simplex pump*** has one drive and one pumping piston; a ***duplex pump*** has two of each. Similar, ***triplex pumps*** have three fluid handling cylinders. These pumps are built as either single or double acting units. Pumps with more than three cylinders are rarely used in fluid power systems.

5.15.5. Graphic Symbols for Pumps

The four different standard symbols used for hydraulic pumps are given below :



(a) Fixed displacement, unidirectional pump
(b) Variable displacement unidirectional pump
(c) Fixed displacement, bidirectional pump
(d) Variable displacement bidirectional pump

5.16. PUMP PERFORMANCE

The performance characteristics of a pump can be represented in terms of overall efficiency. Overall efficiency, in turn, has two components : 'Volumetric efficiency' and 'mechanical efficiency'. These three efficiencies are presented below.

5.16.1. Volumetric Efficiency

✓ ***Definition :*** It is the ratio between the actual flow rate produced by the pump and the theoretical flow rate that the pump should produce.

✓ ***Formula :***

$$\text{Volumetric efficiency} = \frac{\text{Actual flow rate produced by the pump}}{\text{Theoretical flow rate that the pump should produce}} \times 100$$

$$\boxed{\eta_{vol} = \frac{Q_A}{Q_T} \times 100} \qquad \ldots (5.10)$$

✓ ***Significance :*** *The volumetric efficiency indicates the amount of leakage within the pump.* The lower the internal slip losses, the higher the volumetric efficiency. For zero slip, the volumetric efficiency is 100%.

5.16.2. Mechanical Efficiency

✓ ***Definition :*** It is the ratio between the theoretical power required to operate the pump and the actual power delivered to the pump.

✓ ***Formula :***

$$\text{Mechanical efficiency} = \frac{\text{Theoretical power required to opeate the pump}}{\text{Actual power delivered to pump}} \times 100 \qquad \ldots (5.11)$$

or

$$\boxed{\eta_{mech} = \left(\frac{P \times Q_T}{T_A \times \omega}\right) \times 100} \qquad \ldots (5.12)$$

where

P = Pump discharge pressure in N/m^2,

Q_T = Theoretical flow rate of the pump in m^3/s,

T_A = Actual torque delivered to pump in N-m,

ω = Angular speed of the pump in rad/s = $\frac{2\pi N}{60}$, and

N = Speed of the pump in r.p.m.

Mechanical efficiency can also be calculated in terms of torques as follows :

$$\eta_{mech} = \frac{\text{Theoretical torque required to operate pump}}{\text{Actual torque delivered to pump}} \times 100 \qquad \ldots (5.13)$$

$$\boxed{\eta_{mech} = \frac{T_T}{T_A} \times 100}$$

Here

$$\boxed{T_T\,(\text{N.m}) = \frac{V_D\,(\text{m}^3) \times P\,(\text{Pa})}{2\,\pi}} \qquad \ldots (5.14)$$

and

$$T_A = \frac{\text{Actual power delivered to pump (watts)}}{\left(\frac{2\pi N}{60}\right)} \qquad \ldots (5.15)$$

✓ ***Significance :*** The mechanical efficiency indicates the amount of energy lost due to friction in bearings and other mating parts, and energy lost due to fluid turbulence. In other words, *the mechanical efficiency indicates the amount of energy losses that occur due to reasons other than leakages.*

✓ Since the amount of power required to overcome friction rises with increased liquid viscosity, mechanical efficiency decreases as liquid viscosity decreases.

✓ Power losses in timing gears, bearings and seals reduce mechanical efficiency.

5.16.3. Overall Efficiency

✓ ***Definition :*** It is the ratio between the actual power delivered by pump and the actual power delivered to pump.

✓ ***Formula :***

$$\text{Overall efficiency} = \frac{\text{Actual power delivered by pump}}{\text{Actual power delivered to pump}} \times 100 \qquad \ldots (5.16)$$

Mathematically, the overall efficiency can also be written as

$$\eta_0 = \text{Volumetric efficiency} \times \text{Mechanical efficiency}$$

or

$$\eta_0 = \eta_{vol} \times \eta_{mech} \qquad \ldots (5.17)$$

Substituting equations (5.10), (5.12), and (5.17), we get

$$\boxed{\eta_0 = \left(\frac{P \cdot Q_A}{T_A \cdot \omega}\right) \times 100} \qquad \ldots (5.18)$$

✓ ***Significance :*** *The overall efficiency indicates the amount of energy losses by all means.*

Note In our calculations, we may use the terms 'brake power' and 'hydraulic power'. The actual power delivered to a pump from a prime motor (like electric motor) via a rotating shaft is often called by the term ***'brake power'***. Similarly the actual power delivered by a pump to the fluid is called ***'hydraulic power'***.

5.16.4. Comparison of Various Positive Displacement Pumps

Table 5.7 compares the various types of positive displacement pumps.

Table 5.7. Comparison of various positive displacement pumps

Sl.No.	Description	Gear Pumps	Vane Pumps	Piston Pumps
1.	Type of displacement.	Only fixed displacement is possible.	Both fixed and variable displacement are possible.	Both fixed and variable displacement are possible.
2.	Volumetric efficiency.	80 to 90%	82 to 92%	90 to 98%
3.	Discharge pressure range (in bar).	150	250	Above 500
4.	Cost of pump.	Low	Medium	High

5.17. PUMP CHARACTERISTICS

5.17.1. Introduction

- ✓ The control factors for the pump discharge pressure and volume of the fluid are speed of operation and load on the pump.
- ✓ Moreover, pumps of different types will operate differently under similar conditions. For example, the effect of discharge pressure on pump output differs between positive and non-positive displacement pumps.
- ✓ The behaviour of a pump under varying conditions is shown by the curves known as ***characteristics curves*** of the pump.

5.17.2. Pump Discharge Pressure Vs Rate of Discharge

Fig.5.18 depicts the relation between the pressure (or head) produced by the pump and the rate of discharge when the pump is running of constant speed.

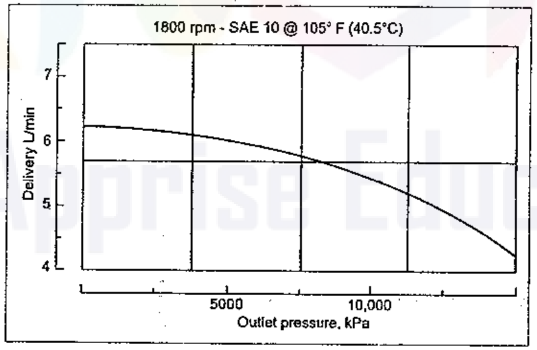


Fig. 5.18. Relation between pump discharge pressure and pump delivery, when the pump speed is constant

From Fig.5.18, it is clear that less the pressure to be delivered, more the rate of discharge.

5.17.3. Pump Discharge Pressure Vs Power, Efficiency, and Rate of Discharge

Fig.5.19 tells us how much power must be supplied to the pump to obtain different rates of discharge against different discharge pressures.

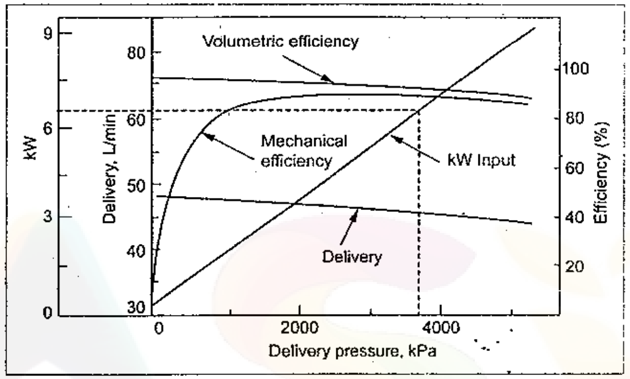


Fig. 5.19. Chart for determining pump power requirements

From Fig.5.19, it is clear that more power is required to deliver higher discharge pressure. These curves also give information about the volumetric efficiency and mechanical efficiency at different discharge pressures.

5.17.4. Rotary Pump Characteristics

Fig.5.20 depicts the typical efficiency curve, power curve, and rate of discharge curve for the rotary pump at constant operational speed.

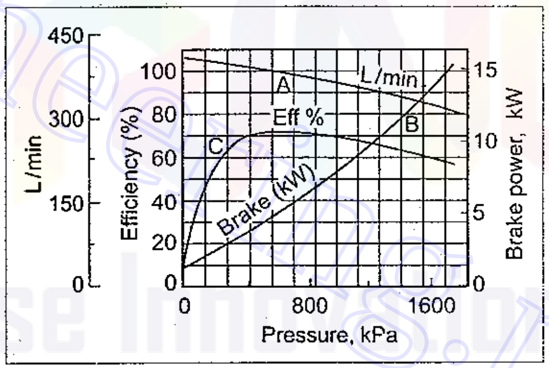


Fig. 5.20. Rotary pump characteristics

From Fig.5.20, we can interpret the following conclusions :

- Rotary pumps usually run more efficiently at lower delivery pressures.
- The power necessary to run a rotary pump increases almost directly, as does the pressure produced by the pump at constant speed.
- There is relatively little difference in the rate of discharge for delivery pressures.

5.17.5. Centrifugal Pump Characteristics

Fig.5.21 depicts the typical efficiency curve, power curve, and rate of discharge curve for the centrifugal pump at constant operational speed.

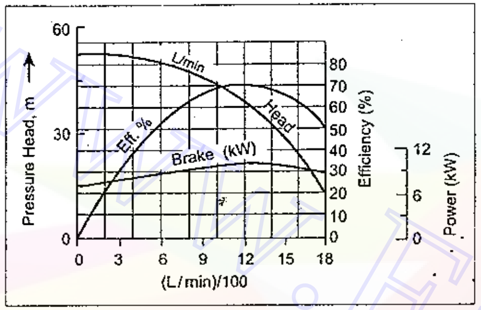


Fig. 5.21. Centrifugal pump characteristics

From Fig.5.21, we can interpret the following conclusions :

- Centrifugal pumps usually run more efficiently at higher rate of discharge.
- The rate of discharge of centrifugal pumps drops quickly as discharge pressure increases.

5.17.6. External Gear Pump Characteristics

- ✓ The typical characteristics curves of an external gear rotary pump is shown in Fig.5.22. These curves show the capacity and power input for an external gear pump at various speeds.

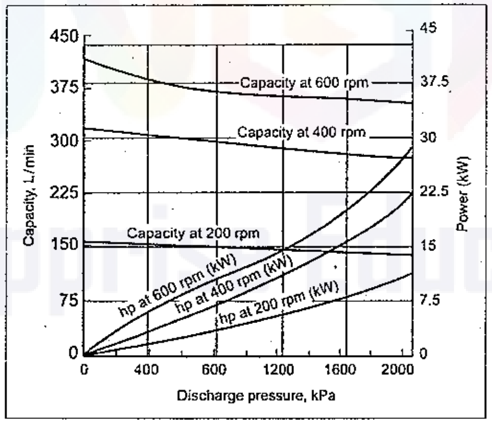


Fig. 5.22. Typical characteristic curves for an external gear pump

- ✓ The curve showing the relation between pump discharge pressure and pump capacity is often termed ***the head-capacity or HQ curve.***

- ✓ The curve showing the relation between the power input and the pump capacity is termed ***the power-capacity or PQ curve.***
- ✓ From Fig.5.22, we can interpret the following conclusions :
  - At any given speed, the capacity characteristic is nearly a flat line.
  - The power input increases with both operating speed and discharge pressure.
  - As the speed of a gear pump is increased, its discharge rate also increases.

5.17.7. Pump Performance Comparison Factors

Table 5.8 compares various performance factors for different types of pumps. Table 5.9 compares the weight-to-power ratio factor for different types of pumps.

Table 5.8. Comparison of various performance factors for pumps

Type of pump	Pressure, bar		Flow rate, litre/min		Speed, rad/s		Efficiency, %		Maximum power, kW†
	Maximum	Common median	Maximum	Common median	Maximum	Common median	Volumetric	Overall	
External gear	300	10–100	400	3–100	350	75–200	65–85	60–70	100
Internal gear	350–400	300	450	200	300	200	98	85–90	125
Fixed vane	175	125	200	5–150	300	150–200	85–90	75–85	50
Variable vane	125	75	–	100–150	300	180	90	85	30
Screw	175	30–60	7500	3–1000	300	150–300	95	75–85	50
Variable axial piston	700	300–350	1000	*	350–400	200–300	95	85–90	150
Bent axis piston	700	250–300	800	*	400	200–300	>95	>90	125
Radial piston	1000	300–400	2000	*	350	150–200	>95	>90	350

* Moderately higher than other pumps.

† General industrial requirement is 25–30 W.

Table 5.9. Comparison of weight-to-power ratio factor for pumps

Type of pump	Ratio	
	Common median , kW	Maximum possible, kg/kW
External gear	0.5–0.75	1.5
Single-stage vane	0.2–1.25	5
Variable axial piston	0.3–0.6	6
Bent axis piston	0.3–2.5	10
Radial piston	0.6–10	20

Note 1. In general, gear pumps are the lest expensive but also provide the lowest level of performance. Since the gear pumps are simple in design and compact in size, therefore they are most commonly used in fluid power systems.

2. The efficiency and the cost of vane pump lies between those of gear and piston pumps. However, clean oil with good lubricity is necessary for its continued satisfactory performance.
3. Among all pumps, piston pumps are the most expensive but provide the highest level of overall performance. They produce a non-pulsating flow and can operate at the highest pressure levels. However, because of their complex design, piston pumps cannot be repaired in the field.

5.18. PUMP PROBLEMS

5.18.1. Pump Noise

- ✓ Noise is a significant factor used to determine the performance of the pumps.
- ✓ Any increase in noise level normally indicates wear and danger of failure of pump.
- ✓ Normally noise is measured in units of decibels (dB).
- ✓ Generated noise levels depend on many factors such as the pump type, pump component materials, pump mountings, rigidity, manufacturing and fitting accuracies of the pump elements, size and flow capacity, pressure, speed of rotation, pressure pulsations, and the other components in the circuit.
- ✓ Table 5.10 presents the approximate noise levels for various pump designs. Generally speaking, external gear and the piston pumps are the noisiest while screw pumps are very quiet; vane and internal gear pumps have noise levels somewhere in between a piston and screw pumps.

Table 5.10. Noise levels for various pump designs

Pump type	Noise level (dB)
Gear	80 – 100
Vane	65 – 85
Piston	60 – 80
Screw	50 – 70

5.18.2. Slip

- ✓ Slip is the leakage occurs between the discharge and suction sides of a pump through the pump clearances.
- ✓ The extent of this leakage depends on the width, length and shape of the clearances, the viscosity of the pumped liquid, and the pressure difference between the discharge and suction sides of the pump.
- ✓ Pump speed does not influence slip. But slip increases with increasing liquid viscosity.

5.18.3. Cavitation

- ✓ ***Definition :*** The formation, growth and collapse of vapour filled cavities or bubbles in a flowing liquid due to local fall in fluid pressure is called cavitation.
- ✓ ***Phenomenon :*** For smooth operation, pumps should be completely filled with liquid. When liquid does not completely fill the pump chamber, a loss of capacity results. This may occur through the vapourization of some of the process liquid in the suction line or the pump chamber. The vapour bubbles are carried into higher-pressure regions of the pump where they collapse, resulting in noise and vibration. This phenomenon is called pump cavitation.
- ✓ ***Effects :*** The pump cavitation may cause severe erosion of the pump components (also called pitting) and reduce the pump life.
- ✓ Cavitation can be avoided by ensuring that the suction pressure is always greater than that required by the pump.

5.18.4. Pump Ripple

Small variations of fluid flow that takes place during pumping (due to some design problems) are called ripple.

5.19. PUMP SELECTION

Pumps are selected by considering number of factors into account. Main factors among these considerations are presented in Table 5.11.

Table 5.11. Checklist for the pump selection

1.	Safe and maximum system working pressures.
2.	Allowable pump speeds.
3.	Rated pump performance.
4.	System flow rate requirements.
5.	Suitability of variable displacement control.
6.	Volumetric and/overall efficiency.
7.	Operating reliability and durability.
8.	Life expectancy at variable loads and speeds.
9.	Cost and economic factors for overall system compatibility.
10.	Oil characteristics and their relationship to rate of pump wear.
11.	Pump noise generation under different speeds, pressures and flow rates.
12.	System temperature.
13.	Manufacturing characteristics : Component clearances and fit.
14.	Compactness and power-to-weight ratio.

SOME ILLUSTRATIVE EXAMPLE PROBLEMS

Problems On Gear Pumps

Example 5.1 *A gear pump has a 80 mm outside diameter, a 55 inside diameter, and a 25 mm width. If the actual pump flow at 1600 rpm and rated pressure is 95 Lpm, what is the volumetric efficiency ?*

Given Data : $D_o = 80$ mm; $D_i = 55$ mm; $L = 25$ mm; $N = 1600$ rpm;

Rated pressure = 95 Lpm.

☺ ***Solution :*** It is given that rated pressure is 95 Lpm (*i.e.*, litres per minute). That means, the actual discharge,

$$Q_A = 95 \text{ Lpm} = 95 \times 10^{-3} \text{ m}^3/\text{min} \qquad [\because 1 \text{ L} = 0.001 \text{ m}^3]$$

We know that the volumetric displacement of the gear pump,

$$V_D = \frac{\pi}{4}(D_o^2 - D_i^2)\, L$$

$$= \frac{\pi}{4}\,[(0.08)^2 - (0.055)^2]\,(0.025) = 6.627 \times 10^{-5} \text{ m}^3/\text{rev}$$

Now, Theoretical discharge,

$$Q_T = V_D \times N$$

$$= (6.627 \times 10^{-5})\,(1600) = 0.106 \text{ m}^3/\text{min}$$

We also know that,

$$\text{Volumetric efficiency, } \eta_{vol} = \frac{Q_A}{Q_T} \times 100 = \frac{95 \times 10^{-3}}{0.106} \times 100 = \mathbf{89.62\%} \quad \textbf{Ans.}$$ ☜

Example 5.2 *Calculate the actual delivery of a gear pump for the following specifications : Module of gear teeth = 6 mm; Number of teeth in driver gear = 18; Gear width = 25 mm; Pressure angle = 20°; Pump speed = 1000 rpm; Volumetric efficiency = 90%.*

Given Data : $m = 6$ mm; $z = 18$; $L = 25$ mm; $\alpha = 20°$; $N = 1000$ rpm; $\eta_{vol} = 90\%$.

☺ ***Solution :*** We know that the theoretical discharge of a gear pump,

$$Q_T = 2\pi\, L\, m^2\, N \left[z + \left(1 + \frac{\pi^2 \cos\alpha}{12} \right) \right] \text{ m}^3/\text{min}$$

$$= 2\pi\,(0.025)\,(6 \times 10^{-3})^2\,(1000) \left[18 + \left(1 + \frac{\pi^2 \cos 20°}{12} \right) \right] = 0.1118 \text{ m}^3/\text{min}$$

Then the actual delivery (*i.e.*, actual discharge) is given by

$$Q_A = \eta_{vol} \times Q_T \qquad \ldots [\because \eta_{vol} = Q_A/Q_T]$$

$$= 0.9\,(0.1118) = \mathbf{0.1006 \text{ m}^3/\text{min}} \text{ or } \mathbf{100.6 \text{ Lpm}} \quad \textbf{Ans.}$$ ☜

Problems on Vane Pumps

Example 5.3 *A vane pump is to have a volumetric displacement of 95 cm³. It has a rotor diameter of 60 mm, a cam ring diameter of 85 mm, and a vane width of 50 mm. What must be the eccentricity ?*

Given Data : $V_D = 95 \text{ cm}^3 = 95 \times 10^{-6} \text{ m}^3$; $D_R = 60$ mm; $D_C = 85$ mm; $L = 50$ mm.

☺ ***Solution :*** We know that the volumetric displacement of the vane pump,

$$V_D = \frac{\pi}{2}(D_C + D_R)\, e\, L$$

or

$$95 \times 10^{-6} = \frac{\pi}{2}\,(0.085 + 0.060)\, e \;\; 0.050$$

or

$$\text{Eccentricity, } e = \mathbf{8.34 \times 10^{-3} \text{ m}} \text{ or } \mathbf{8.34 \text{ mm}} \quad \textbf{Ans.}$$ ☜

Problems on Piston Pumps

Example 5.4 *Find the offset angle for an axial piston pump that delivers 1.25 Lps at 2000 rpm. The pump has nine 12.7 mm diameter pistons arranged on a 130 mm diameter piston circle. The volumetric efficiency is 94%.*

Given Data : $Q_A = 1.25 \text{ Lps} = 1.25 \times 10^{-3} \text{ m}^3/\text{s} = (1.25 \times 10^{-3}) \times 60 = 0.075 \text{ m}^3/\text{min}$; $N = 2000$ rpm; $Y = 9$; $d = 12.7$ mm; $D = 130$ mm; $\eta_{vol} = 94\%$.

☺ ***Solution :*** We know that the theoretical discharge of an axial piston pump,

$$Q_T = D\,A\,N\,Y \tan\theta \;\; \text{m}^3/\text{min}$$

Then the actual discharge,

$$Q_A = Q_T \times \eta_{vol}$$

or

$$Q_A = D\,A\,N\,Y \tan\theta \times \eta_{vol} \qquad \ldots (1)$$

Here

$$A = \text{Area of each piston} = \frac{\pi}{4}\, d^2$$

$$= \frac{\pi}{4}\,(0.0127)^2 = 1.2667 \times 10^{-4} \text{ m}^2$$

Substituting in equation (1), we get

$$0.075 = (130 \times 10^{-3})\,(1.2667 \times 10^{-4}) \times 2000 \times 9 \times \tan\theta \times 0.94$$

or

$$\tan\theta = 0.269$$

or

$$\text{Offset angle, } \theta = \mathbf{15.06°} \quad \textbf{Ans.}$$ ☜

Example 5.5 *Calculate the actual flow rate in units of Lps of a radial piston pump for the following specifications :*

Number of pistons = 9; Diameter of piston = 25 mm; Maximum eccentricity = 10 mm; Speed of rotor = 1800 rpm; Volumetric efficiency = 95%.

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Given Data : Y = 9; $d = 25$ mm; $e = 10$ mm; N = 1800 rpm; $\eta_{vol} = 95\%$.

☺ ***Solution :*** We know that the theoretical discharge of a radial piston pump,

$$Q_T = 0.5\,e\,Y\,\pi\,d^2\,N \quad m^3/min$$

$$= 0.5 \times 0.01 \times 9 \times \pi\,(0.025)^2 \times 1800 = 0.159\ m^3/min$$

Then the actual delivery,

$$Q_A = Q_T \times \eta_{vol}$$

$$= 0.159 \times 0.95 = 0.151\ m^3/min = \frac{0.151 \times 10^3}{60} = \mathbf{2.516\ Lps}$$ **Ans.** ☜

Problems on Pump Efficiencies

Example 5.6 ***A pump of positive displacement type has a mechanical efficiency of 94% and a volumetric efficiency of 92%. What is its overall efficiency ?***

Given Data : $\eta_{mech} = 94\%$; $\eta_{vol} = 92\%$.

☺ ***Solution :*** We know that,

$$\eta_{overall} = \eta_{mech} \times \eta_{vol} = (0.94 \times 0.92) \times 100 = \mathbf{86.48\%}$$ **Ans.** ☜

Example 5.7 ***A pump has a displacement of 80 cm³. It delivers 1.25 Lps at 1200 rpm and 75 bar. If the prime mover input torque is 110 N-m,***

(a) Find the overall efficiency of the pump ?

(b) What is the theoretical torque required to operate the pump.

Given Data : $V_D = 80\ cm^3 = 80 \times 10^{-6}\ m^3$; $Q_A = 1.25$ Lps $= 1.25 \times 10^{-3}\ m^3/s$; N = 1200 rpm; P = 75 bar = $75 \times 10^5\ N/m^2$; T = 90 N.m.

☺ ***Solution :***

$$\omega = \frac{2\pi N}{60} = \frac{2\pi\,(1200)}{60} = 125.66\ rad/s$$

(a) To find overall efficiency of the pump (η_o) :

We know that the volumetric efficiency of a pump,

$$\eta_o = \frac{P \times Q_A}{T_A \times \omega} \times 100 = \frac{(75 \times 10^5)\,(1.25 \times 10^{-3})}{90 \times 125.66} \times 100 = \mathbf{82.89\%}$$ **Ans.** ☜

(b) To find the theoretical torque required to operate the pump (T_T) :

We know that, Theoretical torque, $T_T = \dfrac{V_D \times P}{2\pi}$

$$= \frac{(80 \times 10^{-6})\,(75 \times 10^5)}{2\pi} = \mathbf{95.49\ N\text{-}m}$$ **Ans.** ☜

Example 5.8 ***A pump having a 95% volumetric efficiency delivers 25 Lpm of oil at 1200 rpm. What is the volumetric displacement of the pump ?***

Given Data : $\eta_{vol} = 95\%$; $Q_A = 25$ Lpm $= 25 \times 10^{-3}\ m^3/min$; N = 1200 rpm.

☺ ***Solution :*** We know that,

$$\eta_{vol} = \frac{Q_A}{Q_T} \text{ or } Q_T = \frac{Q_A}{\eta_{vol}} = \frac{25 \times 10^{-3}}{0.95} = 26.31 \times 10^{-3}\ m^3/min$$

We also know that the theoretical discharge,

$$Q_T = V_D \times N$$

or Volumetric displacement, $V_D = \dfrac{Q_T}{N} = \dfrac{26.31 \times 10^{-3}}{1200} = \mathbf{2.193 \times 10^{-5}\ m^3}$ **Ans.** ☜

Example 5.9 ***How much hydraulic power would a pump produce when operating at 125 bars and delivering 1.25 Lps of oil ? What power-rated electric motor would be selected to drive this pump if its overall efficiency is 88% ?***

Given Data : P = 125 bars = $125 \times 10^5\ N/m^2$; $Q_A = 1.25$ Lps $= 1.25 \times 10^{-3}\ m^3/s$; $\eta_0 = 88\%$

☺ ***Solution :*** We know that the actual power delivered to a pump from a prime mover is called 'brake power' and the actual power delivered by a pump to the fluid is called 'hydraulic power'.

We also know that, $\eta_0 = \dfrac{\text{Actual power delivered by pump}}{\text{Actual power delivered to pump}} \times 100$

or $$\eta_0 = \frac{\text{Hydraulic power}}{\text{Brake power}} \times 100 \qquad \ldots (1)$$

(a) To find hydraulic power :

Hydraulic power $= P \times Q_A$

$$= (125 \times 10^5)\,(1.25 \times 10^{-3}) = \mathbf{15.625\ W\ or\ 15.625\ kW}$$ **Ans.** ☜

(b) To find motor power required :

From equation (1),

$$\text{Brake power} = \frac{\text{Hydraulic power}}{\eta_0}$$

$$= \frac{15.625 \times 10^3}{0.88} = \mathbf{17756\ W\ or\ 17.756\ kW}$$ **Ans.** ☜

REVIEW AND SUMMARY

✓ ***A hydraulic pump*** *is a device which converts mechanical energy into hydraulic energy.*

✓ ***Pump classification :***

1. *Positive displacement pumps, and*
   - *(i) Rotary pumps*
     - *(a) Gear pumps, and (b) Vane pumps.*
   - *(ii) Reciprocating pumps*
2. *Non-positive displacement pumps*
   - *(a) Centrifugal pumps, (b) Axial flow pumps, and (c) Radial flow pumps.*

✓ *The* ***positive displacement pumps*** *discharge fixed quantity of fluid into the hydraulic system per revolution of pump shaft rotation.*

✓ *The* ***non-positive displacement*** *(i.e., centrifugal)* ***pumps*** *are used only for transporting fluid from one location to another location. They are not preferred in the fluid power industries because these pumps cannot withstand high pressures.*

✓ *The construction and operation of different types of pumps such as external gear pump, internal gear pump, lobe pump, gerotor pump, screw pump, unbalanced and balanced vane pumps, and axial and radial piston pumps have been discussed in this chapter.*

✓ ***Formulae Summary :***

1. *Theoretical discharge :* $Q_T\ (m^3/min) = V_D\ (m^3/rev) \times N\ (rpm)$

2. *Volumetric efficiency :* $\eta_{vol} = \frac{Q_A}{Q_T} \times 100$

3. *Gear pump volumetric displacement :*

$$V_D = \frac{\pi}{4}\,(D_0^2 - D_i^2)\,L$$

or

$$V_D = 2\pi\,L\,m^2\left[z + \left(1 + \frac{\pi^2 \cos\alpha}{12}\right)\right]$$

4. *Vane pump volumetric displacement :* $V_D = \frac{\pi}{2}\,(D_C + D_R)\,e\,L$

5. *Piston pump volumetric displacement :* $V_D = Y\,A\,D \tan\theta$

6. *Piston pump theoretical flow rate :* $Q_T = Y\,A\,N\,D \tan\theta$

7. *Radial piston pump theoretical flow rate :* $Q_T = 0.5\,e\,Y\,\pi\,d^2\,N$

8. *Pump mechanical efficiency :* $\eta_{mech} = \frac{P\ (Pa) \times Q_T\ (m^3/s)}{T_A\ (N\text{-}m) \times \omega\ (rad/s)} \times 100$

or

$$\eta_{mech} = \frac{T_T}{T_A} \times 100$$

9. *Theoretical torque of a pump :* $T_T = \frac{V_D\ (m^3) \times P\ (Pa)}{2\pi}$

10. *Pump overall efficiency :*

$$\eta_o = \frac{\text{Actual power delivered by pump}}{\text{Actual power delivered to pump}} \times 100$$

or

$$\eta_o = \frac{P\ (Pa) \times Q_A\ (m^3/s)}{T_A\ (N\text{-}m) \times \omega\ (rad/s)} \times 100$$

or

$$\eta_o = \eta_{vol} \times \eta_{mech}$$

✓ *At the end of the chapter, various pump characteristics and about selection of pumps are presented.*

KEY TERMS ONE SHOULD REMEMBER

- **Pump**
- **Positive displacement pumps**
- **Hydrostatic displacement pumps**
- **Fixed displacement pumps**
- **Variable displacement pumps**
- **Non-positive displacement pumps**
- **Hydrodynamic displacement pumps**
- **Gear pumps**
  - **External gear pumps**
  - **Internal gear pumps**
  - **Lobe pumps**
  - **Gerotor pumps**
  - **Screw pumps**
- **Vane pumps**
  - **Unbalanced vane pumps**
  - **Balanced vane pumps**
- **Piston pumps**
  - **Axial piston pumps**
    - **Bent axis type**
    - **Swash plate type**
  - **Radial piston pumps**
- **Volumetric displacement**
- **Theoretical flow rate**
- **Volumetric efficiency**
- **Mechanical efficiency**
- **Overall efficiency**
- **Brake power**
- **Hydraulic power**
- **Pump characteristics**
- **Characteristics curves**
- **Pump performance**
- **Pump noise**
- **Slip**
- **Cavitation**
- **Pump ripple**
- **Pump selection**

REVIEW QUESTIONS

Short Answer Type Questions

On Positive and Non-positive Displacement Pumps

1. What is the function of a hydraulic pump ?
2. Briefly explain the general pumping theory.
3. In what way, pumps differ from compressors and blowers ?
4. How can you classify pumps ?

5. What are positive displacement pumps ? Why are they called 'positive' displacement ?
6. Name any four positive displacement pumps.
7. Why are hydrostatic (or positive) displacement pumps universally used in fluid power industries ?
8. Differentiate between fixed displacement and variable displacement pumps.
9. Why must positive displacement pumps be protected by relief valves ?
10. What do you mean by non-positive displacement pumps ?
11. Where the hydrodynamic (or non-positive) displacement pumps are employed ? Why ?
12. Why are centrifugal pumps not preferred for fluid power applications ?
13. How does a positive displacement pump differ from a centrifugal pump ?

On Gear Pumps

14. Name any four gear pumps used.
15. All the gear pumps are fixed displacement pumps. Why ?
16. What are the advantages of external gear pumps that make them so popular ?
17. How does an external gear pump differ from an internal gear pump ?
18. What type of gears are generally used in gear pumps ?
19. How can you specify a pump ?
20. What are the two ways of varying displacement volumes in gear pumps ?
21. Which pump–external gear, internal gear, screw vane and piston—generates the least noise ? Why ?

On Vane Pumps

22. Name two designs of vane pumps.
23. When do you call a vane pump as a balanced or unbalanced one ?
24. What are the advantages of balanced vane pumps over the unbalanced vane pumps ?
25. How can the unbalanced vane pump be used as a variable displacement pump ?

On Piston Pumps

26. What are piston pumps ? Name the two basic types of piston pumps.
27. How can you vary the displacement in an axial piston pump ?
28. Differentiate between axial and radial piston pumps.

On Pump Performance

29. Define volumetric efficiency of a pump. Write its significance.
30. Define mechanical efficiency of a pump. What does it indicate ?
31. What is overall efficiency of a pump ? What does it mean ?

32. Draw the characteristic curve showing the relation between discharge pressure and rate of delivery of an external gear pump.
33. Sketch any two characteristic curves of the centrifugal pump.
34. What do you mean by 'slip' in pumps ?
35. What is pump cavitation ? What is its cause ?
36. How can you avoid or eliminate pump cavitation ?
37. What is pump ripple ?
38. List some of the factors one should consider while selecting a pump for a specific application.

Essay Answer Type Questions

1. (*a*) Mention the role of a pump in a hydraulic system.
   (*b*) Classify pumps.
   (*c*) Explain how the pumping action in a positive displacement pump is achieved.
2. (*a*) With neat sketch, explain the construction and operation of an external gear pump. Also bring out the advantages and disadvantages of using it.
   (*b*) How does an internal gear pump differ from an external gear pump ?
3. Explain the construction and working of the following with the help of simple sketch for each :
   (*a*) Lobe pump, (*b*) Gerotor pump, and (*c*) Screw pump.
4. With a neat sketch, explain the principle and operation of a vane pump. Also derive an expression for the output of the vane pump.
5. Explain the construction and working of a balanced vane pump, with a neat sketch. Also discuss on the merits and demerits of the pump.
6. (*a*) With a neat sketch, explain the working of axial pump, showing how the discharge can be varied.
   (*b*) Derive an expression for the theoretical discharge of an axial piston pump.
7. Discuss with a neat sketch the working of a swash plate type axial piston pump.
8. (*a*) Compare and comment the performances of the gear, vane, and piston pumps.
   (*b*) Write an engineering brief about the following :
      (*i*) Pump characteristic curves; (*ii*) Pump cavitation;
      (*iii*) Pump noise, and (*iv*) Pump selection.

PROBLEMS FOR PRACTICE

1. A positive displacement pump has an overall efficiency of 88% and a mechanical efficiency of 94%. Find its volumetric efficiency. [*Ans.* 93.62%]

2. A hydraulic system working at a pressure of 100 bars has flow rate of 1.5 Lps, calculate the hydraulic power would a pump produce ?

   [***Hint :*** *Power (W) = P (N/m²) × Q_A (m³/s)*] [*Ans.* 15 kW]

3. A gear pump has a 70 mm outside diameter, a 50 mm inside diameter, and a 25 mm width. If the volumetric efficiency is 88% at rated pressure, what is the corresponding flow rate in units of Lpm. The pump speed is 1200 rpm. [*Ans.* 49.76 Lpm]

4. Calculate the volumetric efficiency of a gear pump for the following specifications : Module of gear teeth = 6 mm; Number of teeth in follower = 16; Gear width = 25 mm; Pressure angle = 20°; Pump speed = 1400 rpm; Flow rate = 125 Lpm. [*Ans.* 88.8%]

5. A vane pump has a rotor diameter of 60 mm, a cam ring diameter of 90 mm, and a vane width of 50 mm. If the eccentricity is 10 mm, determine the volumetric displacement. [*Ans.* 117.81 cm³]

6. Find the flow rate in units of Lpm that an axial piston pump delivers at 1200 rpm. The pump has seven 20 mm diameter pistons arranged on a 150 mm diameter piston circle. The offset angle is set at 12° and the volumetric efficiency is 95%. [*Ans.* 79.93 Lpm]

7. A radial piston pump has the following specifications : Number of plunger = 7; Diameter of plunger = 25 mm; Maximum eccentricity = 10 mm; Pump speed = 1200 rpm; Maximum pressure = 150 bars.

   Calculate (*i*) the theoretical discharge, (*ii*) Actual discharge, (*iii*) Theoretical power required to operate the pump, and (*iv*) Actual power delivered to pump. The volumetric and mechanical efficiencies of the pump are 92% and 82% respectively.

   [***Hint :*** $Q_T = 0.5\ e\ Y\ \pi\ d^2\ N$; $Q_A = Q_T \times \eta_{vol}$; *Theoretical power* = $P\ (N/m^2) \times Q_T\ (m^3/s)$; *Actual power* = *Theoretical power* × η_{mech}]

   [*Ans.* (*i*) 82.47 Lpm; (*ii*) 75.87 Lpm; (*iii*) 20.62 kW; (*iv*) 16.91 kW]

8. A pump has a displacement volume of 100 cm³. It delivers 0.0015 m³/s at 1000 rpm and 7 Mpa. If the prime mover input torque is 120 N-m,

   (*a*) What is the overall efficiency of the pump, and

   (*b*) What is the theoretical torque required to operate the pump.

   [*Ans.* (*a*) 83.56% ; (*b*) 111.41 N-m]

□□

Chapter 6

Hydraulic Actuators : The Transmitter

> *"Few people think no more than two or three times a year; I have made an international reputation for myself by thinking once a week."*
>
> ***– George Bernard Shaw***

> *"Perfection consists not in doing extraordinary things, but in doing ordinary things extraordinarily well."*
>
> ***– Angelique Arnauld***

> *"The pessimist sees difficulty in every opportunity. The optimist sees the opportunity in every difficulty."*
>
> ***– Winston Churchill***

Learning Objectives

While reading and after studying this chapter, you will be able to:

- ☑ Understand and appreciate the principle and uses of actuators.
- ☑ Identify and describe the construction and operation of various types of hydraulic cylinders.
- ☑ Distinguish between a single-acting and a double-acting hydraulic cylinders.
- ☑ Appreciate the mechanism and purpose of a cylinder cushion.
- ☑ Describe the operation and features of tandem, telescopic, and double-rod cylinders.
- ☑ Understand the function of a hydraulic motor and differentiate it with a hydraulic cylinder.
- ☑ Explain the construction and operation of gear, vane, and piston type hydraulic motors.
- ☑ Understand the principle of a limited rotation hydraulic cylinders.
- ☑ Evaluate the hydraulic motors' performance and to determine the design torque and power delivered by hydraulic motors.

CHAPTER 6 HYDRAULIC ACTUATORS : THE TRANSMITTER

6.1. INTRODUCTION

We know that the hydraulic pumps convert the mechanical energy into hydraulic energy. In many fluid power applications, we need to convert the pressure energy of liquid (called hydraulic energy) into mechanical energy to perform useful work. This function is accomplished by the devices known as actuators. Thus actuators are the devices used for converting hydraulic energy into mechanical energy, and therefore have a function opposite to that of pumps. Actuators can be used to produce linear, rotary, or oscillation motion in a hydraulic system.

In this chapter, we shall discuss the principle, construction, operation, and application of various hydraulic actuators and motors employed in a hydraulic system.

6.1.1. What are Actuators ?

- ✓ *Actuators are the devices used for converting hydraulic energy into mechanical energy.*
- ✓ In other words, actuators perform a function just opposite to that of the pumps.
- ✓ The pressurized hydraulic fluid delivered by the hydraulic pump is supplied to the actuators, which converts the energy of the fluid into mechanical energy. This mechanical energy is used to get the work done.
- ✓ The hydraulic actuators produce linear, rotary, or oscillating motion.
- ✓ They can be used for lifting, tilting, clamping, opening, closing, metering, mixing, turning, swinging, counterbalancing, bending and for many other operations.
- ✓ Special applications are on roll-over devices, conveyors, valve operators, printing presses, rock drills, dies, clamps, machine tools, *etc.*

6.1.2. Types of Hydraulic Actuators

Based on the type of motion actuators produce, they are categorized into two :

1. Linear actuators (also called 'hydraulic cylinders'), and
2. Rotary actuators (also called 'hydraulic motors').
   (*a*) Continuous rotary actuators (or simply hydraulic motors), and
   (*b*) Limited rotation rotary actuators (also called 'oscillation fluid motors').

The linear actuators generate motion in a straight line to perform the work. The rotary actuators generate rotary output motion to perform the work.

6.2. LINEAR ACTUATORS (OR HYDRAULIC CYLINDERS)

6.2.1. Introduction

✓ A linear actuator or hydraulic cylinder is a fluid motor that generates linear motion. In other words, *hydraulic cylinder is a device which converts fluid power into linear mechanical force and motion.*

✓ The hydraulic cylinders are basically used for performing work such as pushing, pulling, tilting, and pressing in a variety of engineering applications such as in material handling equipment, machine tools, construction equipment, and automobiles.

6.2.2. Types of Hydraulic Cylinders

The linear hydraulic cylinders can be classified into many types based on various criteria. Some of them are given below :

1. ***Based on the cylinder action :***
   - (*a*) Single acting cylinders, and
   - (*b*) Double acting cylinders.
2. ***Based on the cylinders' design :***
   - (*a*) Plunger or ram cylinders,
   - (*b*) Telescoping cylinders,
   - (*c*) Tandem cylinders,
   - (*d*) Cable cylinders,
   - (*e*) Diaphragm cylinders,
   - (*f*) Bellow cylinders,
   - (*g*) Duplex cylinders, *etc.*
3. ***Based on the cushioning feature :***
   - (*a*) Cushioned type hydraulic cylinders, and
   - (*b*) Non-cushioned type cylinders.
4. ***Based on the piston or plunger used :***
   - (*a*) Piston type cylinders, and
   - (*b*) Plunger type cylinders.
5. ***Based on the cylinders' movement :***
   - (*a*) Rotating type cylinders, and
   - (*b*) Non-rotating type cylinders.

However, we shall present only few important basic hydraulic cylinders in the following sections.

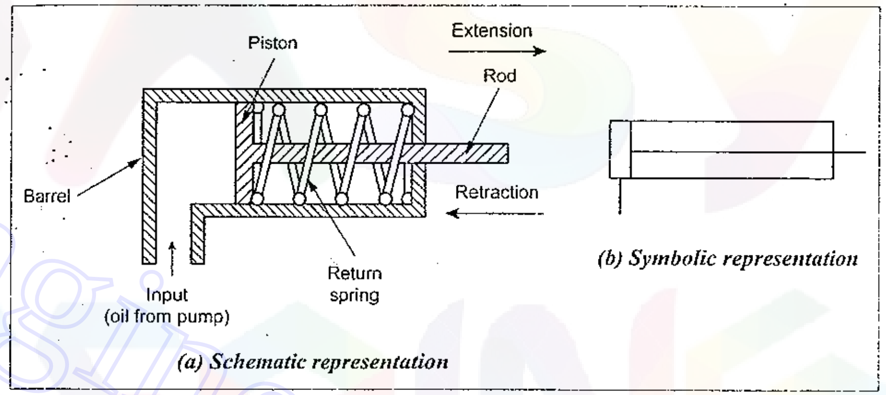
6.3. SINGLE ACTING CYLINDERS

6.3.1. Introduction

As the name suggests, single-acting cylinders can deliver a force in only one direction. The single-acting cylinder is the simplest type of all hydraulic cylinders.

6.3.2. Construction

Single-acting cylinder has only one port at one end of the cylinder barrel to allow the hydraulic fluid. The schematic representation of a single-acting cylinder is depicted in Fig.6.1(*a*). Fig.6.1(*b*) show its symbolic representation. It is designed in such a way that the extending movement is forced by hydraulic fluid and the piston is retracted by gravity or a compression spring.



(a) Schematic representation

(b) Symbolic representation

Fig. 6.1. Single-acting hydraulic cylinder

The piston is assembled inside a cylindrical housing called barrel. To maintain the close fitting between the piston and barrel, piston seal is attached at the circumference of the piston. A rod is connected to the piston and extended out of the barrel to deliver the force. At the other end of the barrel, there is a port for the fluid.

6.3.3. Operation

During the extending action, the force is applied by the pressurized fluid. The force applied to a piston depends on both the area of the piston and the pressure of the fluid. Mathematically, the force applied is given by

$$F = P \times A \qquad \text{... (6.1)}$$

where P = Pressure of the fluid,

A = Area of the piston = $\frac{\pi}{4} D^2$, and

D = Diameter of the piston.

In single-acting cylinders, pistons do not retract hydraulically. But the retraction is accomplished by using gravity or by using the compression spring as shown in Fig.6.1 (*a*). If a cylinder is employed to lift a load, then the load itself can retract the piston.

6.3.4. Advantages and Disadvantages of Single-Acting Cylinders

✓ The single-acting cylinders are very simple to operate, and compact in size.

✓ The single-acting cylinders with spring return cannot be used for larger stroke lengths.

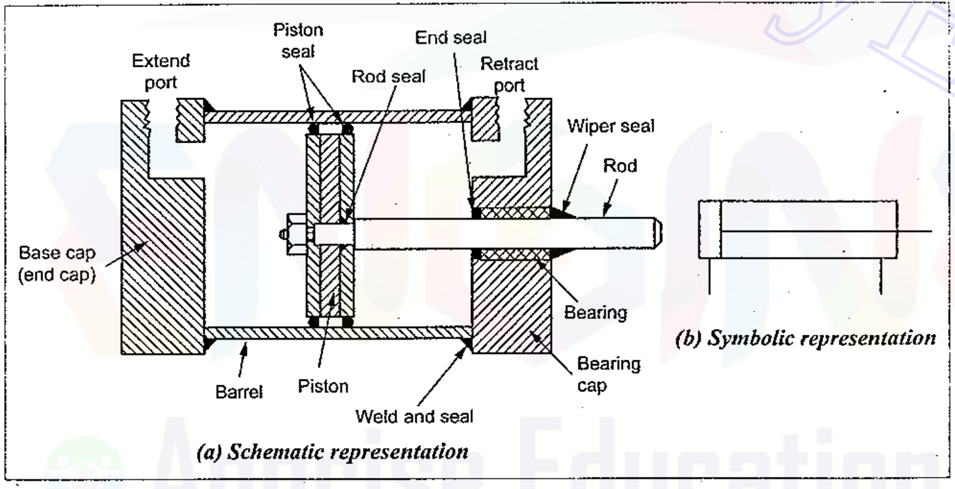
6.4. DOUBLE ACTING CYLINDERS

6.4.1. Introduction

In the double-acting hydraulic cylinders, liquid pressure can be applied to either side of the piston, thereby providing a hydraulic force in both directions. The double-acting cylinders are mostly used in applications where larger stroke lengths are desired.

6.4.2. Construction

Fig.6.2(*a*) shows the construction of a double-acting cylinder and Fig.6.2(*b*) shows its symbolic representation.



(a) Schematic representation

(b) Symbolic representation

Fig. 6.2. Double-acting hydraulic cylinder

The five basic parts of the double acting cylinders are :

1. Base cap with port connections,
2. Bearing cap with port connections,
3. Cylinder barrel,
4. Piston, and
5. Piston rod.

The components are designed in such a way that the end caps and pistons are common to all cylinders of the same diameter, and only barrels and piston rods need to be changed to construct different length cylinders. The end caps are welded to the barrel and the piston rods are threaded to the piston.

In order to prevent wear and leakage, the inner surface of the barrels must be made very smooth. Usually a seamless drawn steel tube is used as a barrel. The cast iron or steel piston is used to transmit force to the piston rod. Also the piston acts as a sliding bearing in the barrel and provide a seal between high and low pressure sides. ***Piston seals*** are provided in between piston and barrel to avoid any leakage. The piston rods are usually made of heat treated chromium alloy to protect it from corrosion and abrasion.

A wiper or scraper seal is fitted on the outside of the piston rod bearing to prevent grit, water or other matter being drawn into the bearing. An internal sealing rings (also called ***O rings***) are fitted behind the bearing to prevent high pressure fluid leaking out along the rod. The end caps have threaded entries for the ports.

6.4.3. Operation

During the extension stroke, the pressurized fluid (usually from the pump) enters through extend port. This fluid moves the piston towards left and the fluid present on the other side is pushed out to the reservoir from the cylinder through retract port.

During the retraction stroke, the fluid is allowed to enter the cylinder through retract port and the piston moves towards right and the fluid present on the other side is pushed out to the reservoir from the cylinder through extend port.

It can be seen from Fig.6.2(*a*) that the volume on both the sides of the piston are different. Since the piston rod is attached at one side only, the cylinder exert greater force when extending [$F = P \times A_{piston}$] than when retraction [$F = P \times (A_{piston} - A_{rod})$]. This results in different pressure levels on either side of the piston and that's why double-acting cylinders are also called as ***differential cylinders.***

Thus the both extension and retraction strokes of the double-acting cylinder provide a linear output motion which can be used to accomplish some useful work.

6.4.4. Analysis of Cylinder Force, Velocity, and Power of a Double-Acting Cylinder

The force, velocity, and power of a double-acting cylinder can be calculated as below :

Let D and d = Diameters of the piston and piston rod respectively,

A_p and A_r = Cross-sectional area of the piston and the piston rod respectively,

F_{ext} and F_{ret} = Hydraulic force acting on piston during the extension and retraction strokes respectively,

v_{ext} and v_{ret} = Velocity of the piston during the extension and retraction strokes respectively,

Q_{in} = Cylinder input volume flow rate in m³/s, and

P = Hydraulic pressure in N/m².

For extension stroke :

$$F_{ext}\,(\text{N}) = P_{ext}\,(\text{N/m}^2) \times A_p\,(\text{m}^2) \qquad \ldots (6.2)$$

$$v_{ext}\,(\text{m/s}) = \frac{Q_{in}\,(\text{m}^3/\text{s})}{A_p\,(\text{m}^2)} \qquad \ldots (6.3)$$

$$\text{Power (kW)} = v_{ext}\,(\text{m/s}) \times F_{ext}\,(\text{kN}) = Q_{in}\,(\text{m}^3/\text{s}) \times \text{P (kN/m}^2) \qquad \ldots (6.4)$$

For retraction stroke :

$$F_{ret}\,(\text{N}) = P_{ret}\,(\text{N/m}^2) \times (A_p - A_r)\ \text{m}^2 \qquad \ldots (6.5)$$

$$V_{ret}\,(\text{m/s}) = \frac{Q_{in}\,(\text{m}^3/\text{s})}{(A_p - A_r)\ \text{m}^2} \qquad \ldots (6.6)$$

$$\text{Power (kW)} = v_{ret}\,(\text{m/s}) \times F_{ret}\,(\text{kN})$$

$$= Q_{in}\,(\text{m}^3/\text{s}) \times P_{ret}\,(\text{kN/m}^2) \qquad \ldots (6.7)$$

6.5. CYLINDER CUSHIONING

6.5.1. What is Meant by Cylinder Cushion ?

When the pressurised fluid is allowed to enter inside the cylinder, the piston accelerates and travels in the cylinder barrel. If the piston is allowed to travel at the same speed till the end of the stroke, it will hit the end cap with a great impact. To avoid this impact, the piston needs to decelerate at the end of the travel. The arrangement made at the end caps to achieve the same is called 'cylinder cushion'.

6.5.2. Construction and Operation

A typical cylinder cushioning arrangement is illustrated in Fig.6.3. Figs.6.3(*a*) and (*b*) show the position of the piston at the start and of the cushioning action, respectively.

As the piston approaches the end of its stroke, the plunger enters the end cap port and thus blocks the free flow. Now the fluid is trapped between the piston and the end cap. This fluid can escape only by passing through the adjustable restrictor, as shown in Fig.6.3(*b*). This fluid flow through the restricted flow path causes the piston to decelerate. The rate of deceleration of the piston can be controlled by the adjustable needle valve. A non-return or check valve is provided to allow free flow of fluid to the cylinder quickly during the return stroke.

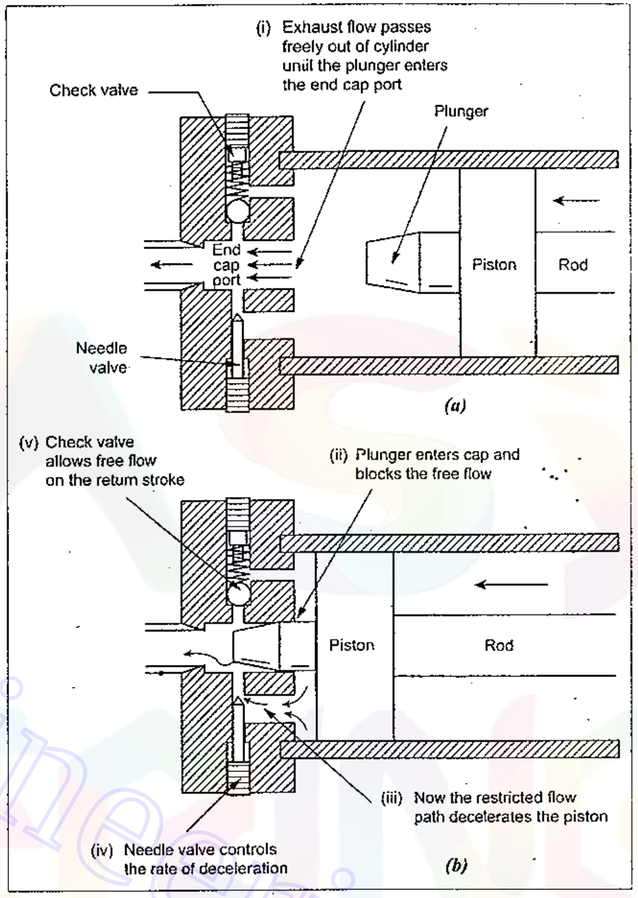

(i) Exhaust flow passes freely out of cylinder until the plunger enters the end cap port
Check valve
Plunger
End cap port
Piston
Rod
Needle valve
(a)
(v) Check valve allows free flow on the return stroke
(ii) Plunger enters cap and blocks the free flow
Piston
Rod
(iii) Now the restricted flow path decelerates the piston
(iv) Needle valve controls the rate of deceleration
(b)

Fig. 6.3. Operation of cylinder cushions

SPECIAL HYDRAULIC CYLINDERS

6.6. TELESCOPIC CYLINDERS

6.6.1. Introduction

Telescopic cylinder is used where there is a space constraint. A telescopic cylinder consists of a series of rams nested in a telescopic assembly which provide a long extension. Such cylinders are useful for applications requiring a long stroke but with only limited space available for the unextended ram. Some of the applications of telescopic cylinders include hydraulic cranes, high-lift fork trucks, dump trucks, dipper wagons, *etc.*

6.6.2. Construction and Operation

Fig.6.4 illustrates the arrangement of a typical telescoping type cylinder having three rams.

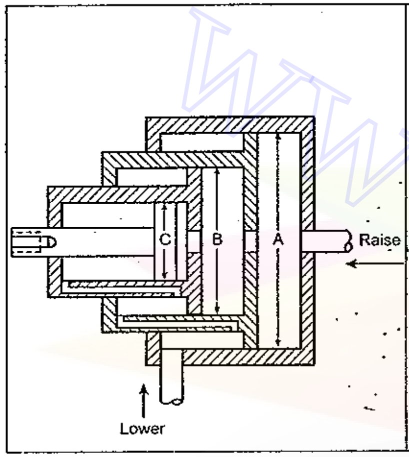


Fig. 6.4. Telescoping cylinder

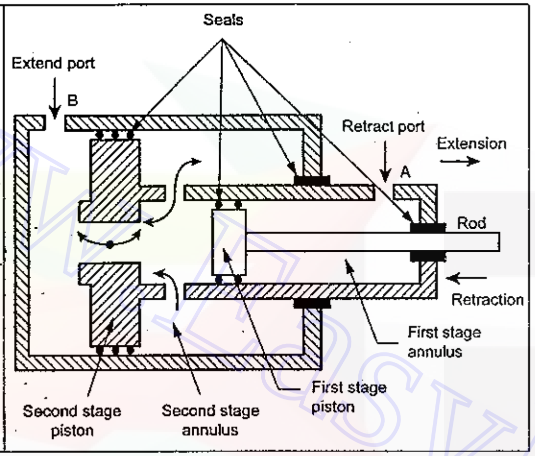


Fig. 6.5. Operation of a two-stage double-acting telescopic cylinder

Since the diameter A of the ram is relatively large, this ram produces a large force for the beginning of the lift of the load.[†] When ram A reaches the end of the stroke, ram B begins to move. Now ram B provides the required smaller force to continue raising the load. When ram B reaches the end of its stroke, then ram C moves outwards to complete the lifting operation. These three rams can be retracted by gravity acting on the load or by pressurized fluid acting on the lip of each ram.

6.6.3. Working of a Two-Stage Double-Acting Telescopic Cylinder

Fig.6.5 illustrate the operation of a typical two-stage double-acting telescopic cylinder.

Retraction stroke : During the retraction stroke, the fluid is fed into the first-stage annulus via retract port A. Therefore the first stage piston is forced to the left until it uncovers the fluid ports connecting this with the second stage annulus. This, in turn, moves the larger piston to the left until both the pistons are fully retracted into the body of the cylinder.

Extension stroke : During the extension stroke, the fluid is fed through the extend port B. Now the fluid forces both pistons to the right until the cylinder is fully extended.

As could be seen from Fig.6.5 that many seals are provided for preventing any possible fluid leakages.

[†] In many fluid power applications, the greatest force is required to begin lifting the load. Once the lifting of load has started, then the required force to continue raising the load will be smaller.

6.7. TANDEM CYLINDERS

6.7.1. Introduction

A tandem cylinder is one in which two or more piston and rod combinations are assembled as a rigid unit with all pistons mounted on single rod. Such cylinders are designed to provide a large working area and thus large forces for a given pressure for a small cylinder diameter. These cylinders are used to obtain a low-force, high-speed action followed by a high-force, low-speed action.

6.7.2. Construction and Operation

Fig.6.6 illustrates a stepped-tandem cylinder, in which two pistons of different sizes mounted on one rod. It contains two cylinders that slide inside each other. Since two cylinders are arranged in series, the tandem cylinder produces the large force (almost double). However, its drawback is that they occupy more linear space.

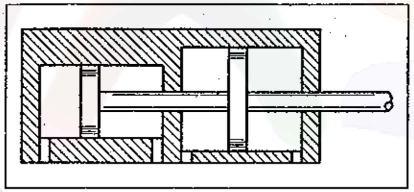


Fig. 6.6. Stepped-tandem cylinder

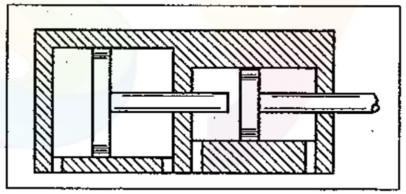


Fig. 6.7. Dual linear actuator

6.7.3. Dual Linear Actuator

The another modification of tandem cylinders is the dual cylinder designs. A dual linear actuator is shown in Fig.6.7. The piston and rod assemblies of a dual actuator are not fastened together as in the tandem actuator. In most dual actuator designs, a given piston acts on another only in one direction.

6.8. DOUBLE-ROD CYLINDERS (OR THROUGH ROD CYLINDERS)

A double-rod cylinder, also known as through rod cylinder, has piston rods extending from both ends of the cylinder. Fig.6.8 illustrates a double-rod cylinder. These cylinders produce equal force and speed on both sides of the cylinder.

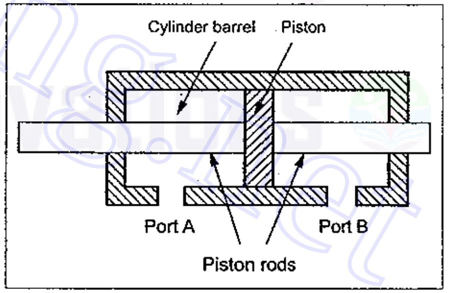


Fig. 6.8. Double-rod cylinder

Note

1. One of the advantageous features of linear actuators (*i.e.*, hydraulic cylinders) is the variety of ways in which they can be mounted in a system. Several mounting arrangements are illustrated in Article 5, Appendix I.

2. The nature of the force provided by a linear actuator depends on the kinematic linkage between the straight-line output of the cylinder and the point at which the force and motion are utilized. Because of the many alternatives in the design of the linkage, the linear actuator can be used to produce linear, rotary, or oscillatory motion. The various applications of linear actuators are illustrated in Article 6, Appendix I.

6.9. ROTARY ACTUATORS (OR HYDRAULIC MOTORS)

6.9.1. Introduction

- ✓ *The function of a rotary actuator is to convert hydraulic energy into rotary mechanical energy.*
- ✓ Rotary actuators are the hydraulic equivalents of electric motors. Hence rotary actuators are also called as ***hydraulic motors.***
- ✓ The hydraulic motors are very much identical in construction and size to rotary type pumps. They work on exactly the reverse principle to that of rotary pumps.
- ✓ Instead of pushing the fluid as pumps do, in a hydraulic motor the rotating elements (*i.e.*, vanes, gears, pistons, *etc.*) are pushed by the pressurized fluid. This enables the hydraulic motor to develop the necessary output torque and rotating motion.
- ✓ The hydraulic motors are usually rated/specified in terms of the torque developing capacity or differential pressure.

6.9.2. Classification of Hydraulic Motors

The hydraulic motors can be classified based on their degree of angular movement as :

1. Continuous rotary hydraulic motors, and
   (*i*) Gear motors, (*ii*) Vane motors, and (*iii*) Piston motors.
2. Limited rotation hydraulic motors[†]
   (*i*) Vane type, and (*ii*) Piston type.

Now we shall discuss the construction and operation of gear, vane, and piston motors, in the following sections.

I. CONTINUOUS ROTARY HYDRAULIC MOTORS

6.10. GEAR MOTORS

6.10.1. Introduction

Like gear pumps, gear motors are fixed displacement devices. Also, gear motors can be classified as external or internal gear units. External gear motors include the gear-on-gear units such as the spur gear motor. Internal gear motors include the crescent seal types and the gerotor type unit.

6.10.2. Construction and Operation

Fig.6.9 illustrates the operation of a gear motor. In this type, both the gear wheels are driven and one of the gear wheel has an extended shaft to provide output torque.

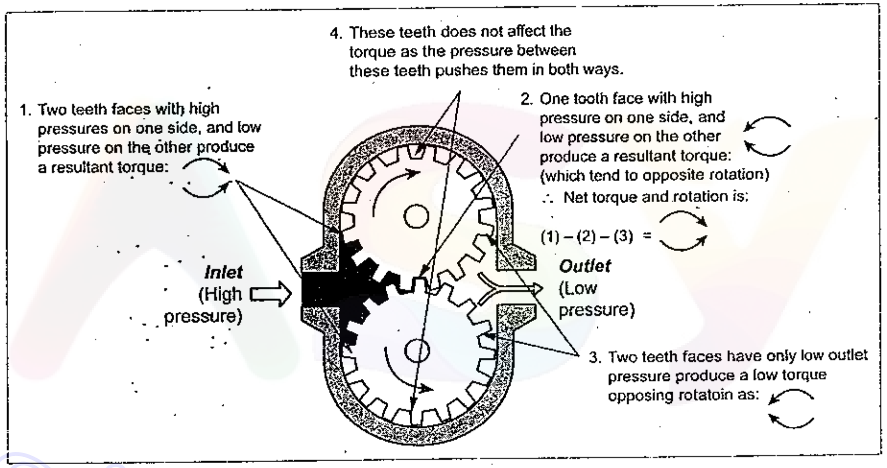

4. These teeth does not affect the torque as the pressure between these teeth pushes them in both ways.
1. Two teeth faces with high pressures on one side, and low pressure on the other produce a resultant torque:
2. One tooth face with high pressure on one side, and low pressure on the other produce a resultant torque: (which tend to opposite rotation)
∴ Net torque and rotation is:
(1) – (2) – (3) =
Inlet
(High pressure)
Outlet
(Low pressure)
3. Two teeth faces have only low outlet pressure produce a low torque opposing rotatoin as:

Fig. 6.9. Torque development by a gear motor

In the gear motor, rotary motion is produced by the unbalanced hydraulic forces on the gear teeth. The hydraulic imbalance in a gear motor is caused by gear teeth unmeshing. As gear teeth unmesh, all teeth subjected to system pressure are hydraulically balanced, except for one side of one tooth on one gear. This imbalance of force on gears, as shown in Fig.6.9, develops the torque. It should be noted that the larger the gear tooth or higher the pressure, more is the torque produced.

6.10.3. Advantages of Gear Motors

The gear motors are simple in design, and very cheap in cost.

6.10.4. Disadvantages of Gear Motors

- ✓ Gear motors are subjected to relatively high internal leakage. Therefore, they are not suitable for high torque, low speed applications.
- ✓ The high pressure at the inlet, coupled with the low pressure at the outlet, generates very high bearing loads.

6.10.5. Ranges

- ✓ The gear motors are available for peak operating pressures upto about 125 bars, with rated capacities upto 10 Lps, and maximum speeds of about 3000 rpm.

[†] These motors provide rotary output motion over a finite angle. That is, the rotation of the shaft of these motors is less than 360°. (Usually 90°, 180°, or 270°).

6.11. VANE MOTORS

6.11.1. Introduction

Vane motors work on the same principle as vane pumps in reverse. In these motors, the pressurised fluid acting on the vanes cause them to rotate and thus developing the torque output. They are suitable for low speed applications than gear motors.

6.11.2. Construction and Operation

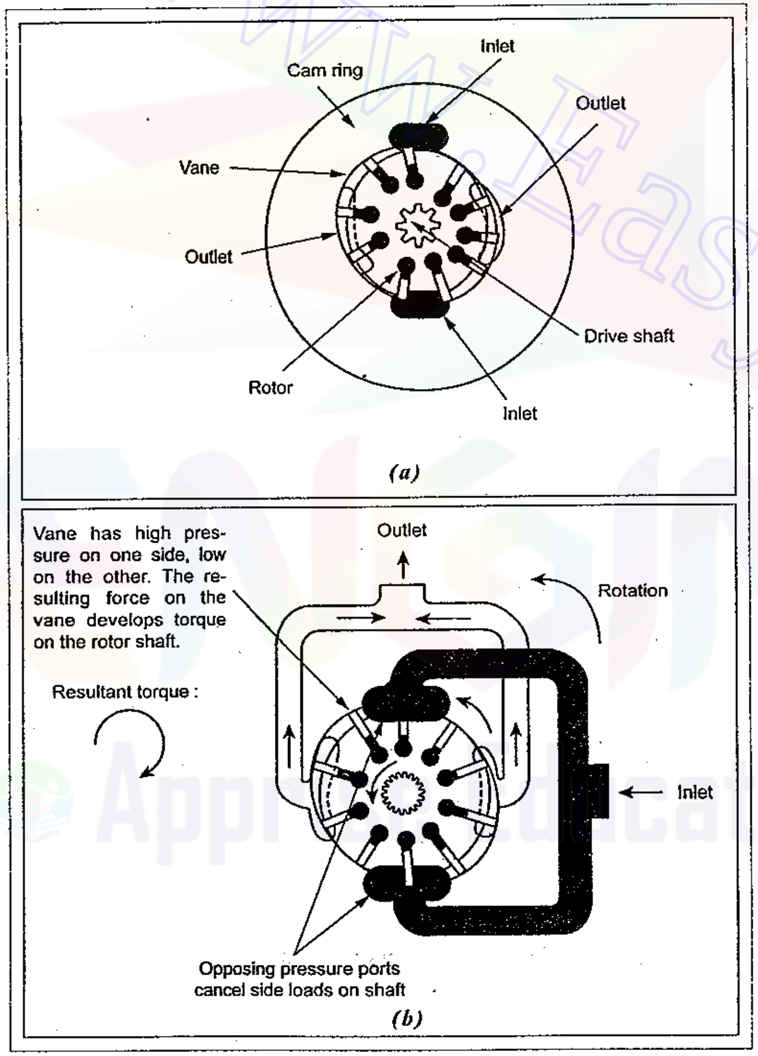

Inlet
Cam ring
Outlet
Vane
Outlet
Drive shaft
Rotor
Inlet
(a)
Vane has high pressure on one side, low on the other. The resulting force on the vane develops torque on the rotor shaft.
Outlet
Rotation
Resultant torque :
Inlet
Opposing pressure ports cancel side loads on shaft
(b)

Fig. 6.10. Operation of a balanced vane motor

Like vane pumps, vane motors can be classified as unbalanced or balanced vane motors. But most vane motors used universally are of the balanced-rotor type. Because hydraulic unbalance causes large radial bearing loads which limit the use of unbalanced vane motors to low pressure operation. Therefore most vane motors have a mechanical configuration similar to that of the balanced vane pump. Also balanced vane motors are fixed-displacement units.

Fig.6.10 illustrates the construction and operation of a balanced-type vane motor.

The vane motor produces torque by the hydraulic pressure that acts on the exposed surfaces of the vanes, which slide in and out of the rotor connected to the driver shaft. To accommodate starting and low-speed operation, it is usually necessary to provide a force, in addition to the centrifugal force, to move the vane radially outward. Springs are commonly used for this purpose. The larger the exposed area of the vane, or higher the pressure, more is the torque developed. Also, as the inlet connects to two opposing pressure passages, the side loads on the rotor are balanced with each other (Fig.6.10(*b*)).

6.11.3. Advantages of Vane Motors

The vane motors have relatively less internal leakage than gear motors. Also the balanced vane motors eliminate the side and bearing loads.

6.11.4. Disadvantages of Vane Motors

Vane type motors, like gear motors, do not generate maximum torque at very low speeds, due to internal leakage. So both gear and vane type motors are not suitable for vehicle drive applications.

6.11.5. Ranges

Vane motors are available at pressure ratings to about 175 bars, with rated capacities upto 15 Lps, and at speeds up to 4000 rpm.

6.12. PISTON MOTORS

6.12.1. Introduction

- ✓ Piston motors are positive displacement motors which can develop an output torque at the shaft by allowing pressurised fluid to act on the pistons.
- ✓ The piston motors can be either fixed or variable-displacement devices.
- ✓ They are suitable for low speed, high torque traction applications such as earth-moving machinery, agricultural tractors, railway locomotive and other industrial applications.
- ✓ The piston motors are the most efficient and can operate at the highest speeds and pressures, when compared to gear and vane type motors.
- ✓ *Types :* Piston motors can be classified in terms of the piston motion as :
  1. Axial-piston motors, and
  2. Radial-piston motors.

6.12.2. Axial Type Piston Motors

Construction and Operation : The operation of an axial type piston motor is essentially the same as that of an axial piston pump except for the direction of flow (refer Section 5.14, and Fig.5.11)

The pressurised liquid introduced through the motor inlet forces the piston assembly against the thrust cam or swash/wobble plate. The angular application of this force causes the plate to rotate and this rotation is transmitted by the shaft. The displacement can be varied by changing the angle of the thrust cam.

6.12.3. Radial Type Piston Motors

Construction and Operation : The operation of a radial type piston is also essentially the same as that of an radial piston pump except for the direction of flow (refer Section 5.15 and Fig.5.17). Fluid enters the piston chamber through a central eccentric cam. The piston is forced radially outward against the thrust ring, thereby producing a force tangent to the piston chamber. The resulting torque causes the shaft to rotate.

6.12.4. Advantages of Piston Motors

- ✓ The piston motors exhibit very high volumetric efficiencies.
- ✓ They produce very high torque.
- ✓ They are capable of working at very high pressures and speeds.
- ✓ They are available in both fixed and variable type displacement units.

6.12.5. Disadvantages of Piston Motors

- ✓ The cost per horse power is relatively high.
- ✓ The power-to-weight ratio of piston motors are comparatively less as that of gear and vane motors.

6.12.6. Ranges

The piston motors are available at pressure ratings upto 350 bars, with rated capacities upto 30 Lps and at operating speeds of 12,000 rpm.

II. LIMITED ROTARY ACTUATORS

6.13. LIMITED ROTATION HYDRAULIC MOTORS

6.13.1. Introduction

- ✓ The limited-rotation motors provide an oscillating power output. In other words, limited-rotation motors provide rotary output motion over a finite angle. Usually the rotation of the shaft of these motors is 90°, 180°, or 270°.

- ✓ ***Types :*** The two types of limited-rotation motors used to obtain an oscillatory output are :
  1. Vane type limited rotation motors, and
  2. Piston type limited rotation motors.

6.13.2. Vane Type Limited Rotation Motors

There are two types of limited rotation vane motors, the single-vane and the double-vane. Fig.6.11 and 6.12 illustrate the operation of a typical single-vane and double-vane rotation motors respectively. In both the single- and the double-vane units, seals are maintained between the rotor and the barriers, and between the vanes and the housing.

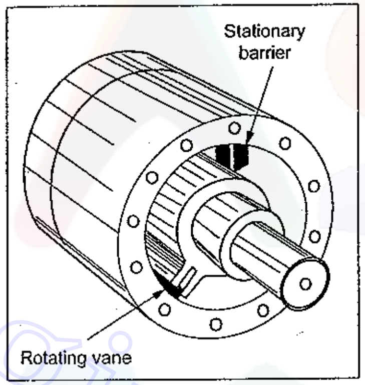


Fig. 6.11. Single-vane rotation motor

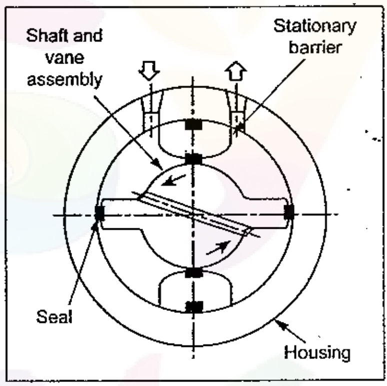


Fig. 6.12. Double-vane rotation motor

6.13.2.1. Single-Vane Rotation Motor

As shown in Fig.6.11, the single-vane unit consists of a cylindrical housing, a shaft with a single vane, a barrier which limits the vane rotation, and end pieces which support the shaft. Pressurised liquid enters on the side of the vane, forcing the vane to rotate to the barrier. The single-vane unit produce the rotation of approximately 280°.

6.13.2.2. Double-Vane Rotation Motor

In the double-vane unit, the pressurised fluid enters on one side of a vane and is ported through the shaft to the corresponding side of the other vane, as shown in Fig.6.12. A rotation of about 100° can be obtained with the double-vane unit.

6.13.2.3. Analysis of Torque Capacity in a Single-Vane Type Limited Rotation Motor

The torque producing capacity of a single-vane type limited rotation motion can be determined as below.

Let T = Torque developing capacity in N-m,

F = Hydraulic force acting on vane in N,

P = Hydraulic pressure in N/m^2,

A = Surface area of vane in contact with liquid in m^2,

R_R = Outer radius of rotor in m,

R_V = Outer radius of vane in m, and

L = Width of vane in m.

$$\text{Area of vane surface, } A = (R_V - R_R)\,L$$

$$\text{The hydraulic force acting on the vane, } F = \begin{Bmatrix}\text{Hydraulic}\\ \text{pressure}\end{Bmatrix} \times \begin{Bmatrix}\text{Vane}\\ \text{surface area}\end{Bmatrix}$$

$$= P \times A = P\,(R_V - R_R)\,L$$

We know that the torque developing capacity,

$$T = \text{Vane force} \times \text{Mean radius of the vane}$$

$$= [\,P\,(R_V - R_R)\,L]\left(\frac{R_V + R_R}{2}\right)$$

or

$$\boxed{T = \frac{P\,L}{2}\,(R_V^2 - R_R^2)\,L} \quad \ldots (6.8)$$

We also know that,

$$\text{Volumetric displacement, } \boxed{V_D = \pi\,(R_V^2 - R_R^2)\,L} \quad \ldots (6.9)$$

Combining equations (6.8) and (6.9), we get

$$\boxed{T = \frac{P \cdot V_D}{2\pi}} \quad \ldots (6.10)$$

It can be noted from Equation (6.10) that torque capacity depends only on the hydraulic pressure and the volumetric displacement.

6.13.2.4. Ranges

The limited-rotation vane motors are available with torque output ranging from less than 1 N-m at 4 bars to nearly 85 kN-m at 200 bars.

6.13.3. Piston Type Limited Rotation Motors

Fig.6.13 illustrates a typical piston type limited rotation motor called ***helix-spline rotary motor.***

As shown in Fig.6.13, the helix-spline unit employs a shaft with a helical screw which passes through the piston. A guide rod prevents rotation of the piston. Also a self-locking helix angle prevents rotation when an external torque is applied. This type of motors can obtain any desired rotation angle. Both lesser and greater than 360° are possible.

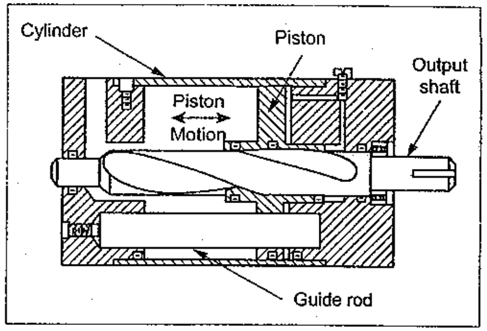


Fig. 6.13. Helix-spline rotary actuator

6.13.4. Applications of Limited Rotation Hydraulic Motors

The important applications of limited rotation hydraulic motors include conveyor sorting, valve turning, air bending operations, flip over between work stations, positioning for welding, lifting, rotating, and dumping.

6.14. HYDRAULIC MOTOR PERFORMANCE

Like in hydraulic pumps, the performance of hydraulic motor is also evaluated by using volumetric, mechanical, and overall efficiencies.

6.14.1. Volumetric Efficiency (η_{vol})

The volumetric efficiency of a hydraulic motor is the inverse of that for a pump. Mathematically,

$$\boxed{\eta_{vol} = \frac{\text{Theoretical flow rate motor should consume}}{\text{Actual flow rate consumed by motor}} \times 100 = \frac{Q_T}{Q_A} \times 100} \ldots (6.11)$$

6.14.2. Mechanical Efficiency (η_{mech})

The mechanical efficiency of a hydraulic motor is the inverse of that for a pump. Mathematically,

$$\boxed{\eta_{mech} = \frac{\text{Actual torque delivered by motor}}{\text{Torque motor should theoretically deliver}} \times 100 = \frac{T_A}{T_T} \times 100} \quad \ldots (6.12)$$

where $$T_A = \frac{\text{Actual power delivered by motor (watts)}}{\text{Angular speed of motor shaft (rad/s)}} = \frac{P}{\omega}, \text{ and}$$

$$T_T = \frac{V_D\,(\text{m}^3/\text{rev}) \times P\,(\text{N/m}^2)}{2\pi} \quad \ldots (6.13)$$

6.14.3. Overall Efficiency (η_0)

The overall efficiency of the hydraulic motor is the product of the volumetric and mechanical efficiencies. Mathematically,

$$\boxed{\eta_0 = \eta_{vol} \times \eta_{mech}} \qquad \ldots (6.14)$$

Combining equations (6.11), (6.12), (6.13), and (6.14), we get

$$\boxed{\eta_0 = \frac{T_A \text{ (N-m)} \times \omega \text{ (rad/s)}}{P \text{ (N/m}^2) \times Q_A \text{ (m}^3\text{/s)}} \times 100} \qquad \ldots (6.15)$$

Note The actual power delivered to a motor by the fluid is called by the term ***'hydraulic power'.*** Similarly, the actual power delivered to a load by a motor via a rotating shaft is called ***'brake power'.***

6.15. HYDRAULIC MOTOR PERFORMANCE CURVES

The characteristic curves of a particular rotary hydraulic motor are nearly identical with those of the corresponding hydraulic pump.

✓ Typical characteristic curves for spur-gear hydraulic motor is given in Fig.6.14.

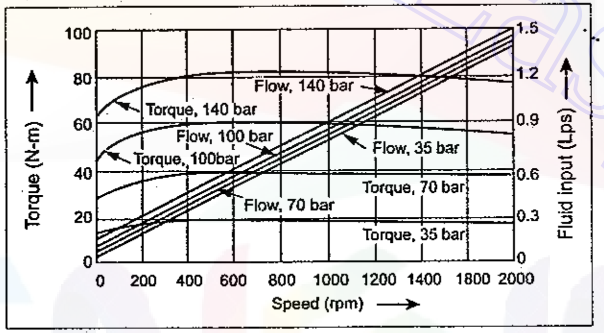


Fig. 6.14. Typical operating characteristic curves for a spur gear hydraulic motor

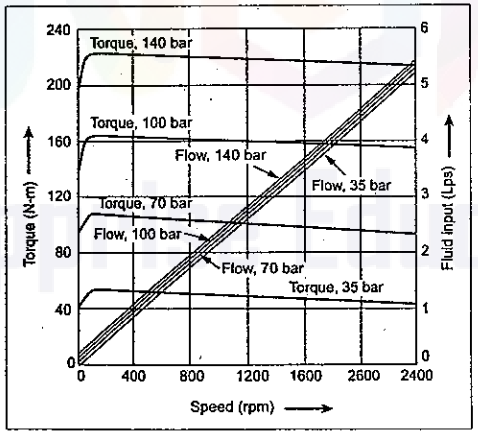


Fig. 6.15. Typical operating characteristic curves for a vane hydraulic motor

✓ Fig.6.15 shows the characteristic operating curves for a vane type hydraulic motor.

✓ Fig.6.16 shows a typical performance curve for a piston type hydraulic motor.

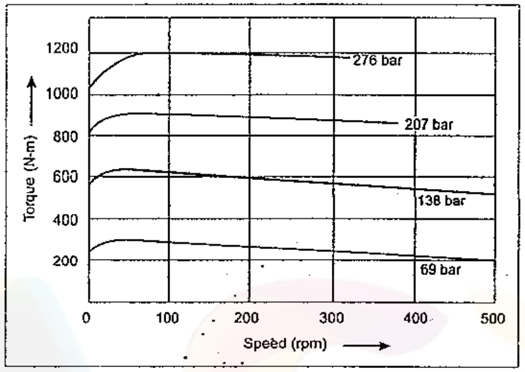


Fig. 6.16. Performance curves for a piston type hydraulic motor

Note In many applications, the fluid power circuit consists of some suitable combination of pump and motor with the necessary piping. These are known as ***fluid transmission devices.*** A fluid transmission is a device which converts mechanical power into fluid power, transports this power, and then converts it back into mechanical power.

SOME ILLUSTRATIVE NUMERICAL PROBLEMS

Problems on Hydraulic Cylinders

Example 6.1 *A hydraulic cylinder is to compress a car body in 8 seconds. The operation requires a stroke of 2.5 m and a force of 45,000 N. If a 8 N/mm² pump has been selected, find the following :*

(i) Required piston area and piston diameter.

(ii) The necessary pump flow.

(iii) The hydraulic power capacity in kW. *[A.U., Nov./Dec'2002]*

Given Data : $t = 8$ s ; $L = 2.5$ m ; $F = 45{,}000$ N ; $P = 8$ N/mm².

☺ ***Solution :*** It is understood that this hydraulic system uses a single-acting hydraulic cylinder.

(i) To find piston area (A_p) and piston diameter (D) :

We know that, $$P = \frac{F}{A_p}$$

or $$8 \times 10^6 = \frac{45000}{A_p}$$

or Required piston area, A_p = $\mathbf{5.625 \times 10^{-3}}$ **m²** **Ans.** ☜

$$\text{Area of piston, } A_p = \frac{\pi}{4} D^2 = 5.625 \times 10^{-3}$$

or Piston diameter, D = **0.0846 m** or **84.6 mm** **Ans.** ☜

(ii) To find the pump flow rate (Q_{in}) :

$$\text{Velocity of pump, } v_p = \frac{\text{Cylinder stroke}}{\text{Time required to complete a stroke}} = \frac{2.5}{8}$$

$$= 0.3125 \text{ m/s}$$

$$\therefore \quad \text{Pump flow rate, } Q_{in} = A_p \times v_p = (5.625 \times 10^{-3})(0.3125)$$

$$= \mathbf{1.758 \times 10^{-3}\ m^3/s} \text{ or } \mathbf{1.758\ Lps}$$ **Ans.** ☜

(iii) To find the hydraulic power capacity in kW :

$$\text{kW power} = v_p \text{(m/s)} \times F \text{(kN)} = (0.3125)(45) = \mathbf{14.06\ kW}$$ **Ans.** ☜

or

$$\text{kW power} = Q_{in} \text{(m}^3\text{/s)} \times P \text{(kN/m}^2\text{)} = (1.758 \times 10^{-3})(8 \times 10^3)$$

$$= \mathbf{14.06\ kW}$$ **Ans.** ☜

Example 6.2 *A pump supplies oil at 1.5 Lps to a 50 mm diameter double-acting hydraulic cylinder. If the load is 4300 N (extending and retracting) and the rod diameter is 25 mm, find :*

- *(i) Hydraulic pressure during the extending stroke.*
- *(ii) Piston velocity during the extending stroke.*
- *(iii) Cylinder kW power during the extending stroke.*
- *(iv) Hydraulic pressure during the retracting stroke.*
- *(v) Piston velocity during the retracting stroke.*
- *(vi) Cylinder kW power during the retracting stroke.*

Given Data : $Q_{in} = 1.5 \text{ Lps} = 1.5 \times 10^{-3} \text{ m}^3\text{/s}$; $D = 50$ mm;

$F_{ext} = F_{ret} = 4300$ N; $d = 25$ mm.

☺ *Solution :*

$$A_p = \frac{\pi D^2}{4} = \frac{\pi (0.050)^2}{4} = 1.963 \times 10^{-3} \text{ m}^2$$

and

$$A_r = \frac{\pi d^2}{4} = \frac{\pi (0.025)^2}{4} = 4.91 \times 10^{-4} \text{ m}^2$$

(i) To find the hydraulic pressure during the extending stroke (P_{ext}) :

$$P_{ext} = \frac{F_{ext}}{A_p} = \frac{4300}{1.963 \times 10^{-3}} = \mathbf{21.9 \times 10^5\ N/m^2} \text{ or } \mathbf{21.9\ bars}$$ **Ans.** ☜

(ii) To find the piston velocity during the extending stroke (v_{ext}) :

$$v_{ext} = \frac{Q_{in}}{A_p} = \frac{1.5 \times 10^{-3}}{1.963 \times 10^{-3}} = \mathbf{0.764\ m/s}$$ **Ans.** ☜

(iii) To find the cylinder kW power during the extending stroke :

$$(\text{kW power})_{ext} = v_{ext} \text{ (m/s)} \times F_{ext} \text{ (kW)} = (0.764)(4.3) = \mathbf{3.28\ kW}$$ **Ans.** ☜

(iv) To find the hydraulic pressure during the retracting stroke (P_{ret}) :

$$P_{ret} = \frac{F_{ret}}{(A_p - A_r)} = \frac{4300}{(1.963 \times 10^{-3} - 4.91 \times 10^{-4})}$$

$$= \mathbf{29.2 \times 10^5\ N/m^2} \text{ or } \mathbf{29.2\ bars}$$ **Ans.** ☜

(v) To find the piston velocity during the retracting stroke (v_{ret}) :

$$v_{ret} = \frac{Q_{in}}{(A_p - A_r)} = \frac{1.5 \times 10^{-3}}{(1.963 \times 10^{-3} - 4.91 \times 10^{-4})} = \mathbf{1.02\ m/s}$$ **Ans.** ☜

(vi) To find the cylinder kW power during the retracting stroke :

$$(\text{kW power})_{ret} = v_{ret} \text{ (m/s)} \times F_{ret} \text{ (kN)} = (1.02)(4.3) = \mathbf{4.386\ kW}$$ **Ans.** ☜

It may be noted that the cylinder supplies the more kW power during the retraction stroke than the extending stroke.

Problems on Hydraulic Motors

Example 6.3 *A single-vane rotary actuator has the following data :*

Outside radius of rotor = 12 mm; Outer radius of vane = 38 mm; Width of vane = 25 mm; Hydraulic pressure developed = 70 bars

Find : (i) the hydraulic force acting on the vane, and (ii) the torque generating capacity of the rotary actuator.

Given Data : $R_R = 12$ mm ; $R_V = 38$ mm ; $L = 25$ mm; $P = 70 \text{ bars} = 70 \times 10^5 \text{ N/m}^2$

☺ *Solution :* We know that the surface area of vane in contact with fluid,

$$A = (R_V - R_R)\, L = (0.038 - 0.012)\, 0.025 = 6.5 \times 10^{-4} \text{ m}^2$$

(i) To find the hydraulic force acting on the vane (F) :

$$F = PA = (70 \times 10^5)(6.5 \times 10^{-4}) = \mathbf{4550\ N}$$ **Ans.** ☜

(ii) To find the torque capacity (T) :

$$T = \frac{PL}{2} (R_V^2 - R_R^2)$$

$$= \frac{(70 \times 10^5)(0.025)}{2} [(0.038)^2 - (0.012)^2] = \mathbf{113.75\ N\text{-}m}$$ **Ans.** ☜

Example 6.4 *A hydraulic motor has a 82 cm³ volumetric displacement. If it has a pressure valve setting for 70 bars and it receives oil from a 0.006 m³/s pump, find : (i) the motor speed, (ii) torque capacity, and (iii) power capacity of the motor.*

[A.U., Nov/Dec. 2004]

Given Data : $V_D = 82\text{ cm}^3 = 82 \times 10^{-6}\text{ m}^3$; $P = 70\text{ bar} = 70 \times 10^5\text{ N/m}^2$; $Q = 0.006\text{ m}^3/\text{s}$.

☺ ***Solution :***

(i) To find the motor speed (N) :

We know that, $$Q = \frac{V_D \times N}{60}$$

or $$0.006 = \frac{(82 \times 10^{-6})}{60} N \quad \text{or} \quad \mathbf{N = 4390\ rpm} \quad \textbf{Ans.} ☜$$

(ii) To find the torque capacity (T) :

$$\therefore \quad T = \frac{P\,V_D}{2\pi} = \frac{(70 \times 10^5)(82 \times 10^{-6})}{2\pi} = \mathbf{91.35\ N\text{-}m} \quad \textbf{Ans.} ☜$$

(iii) To find the power capacity of the motor :

$$\text{Power} = \text{Torque} \times \text{Angular velocity} = T \times \omega = T\left(\frac{2\pi N}{60}\right)$$

$$= 91.35\left(\frac{2\pi \times 4390}{60}\right) = \mathbf{42\ kW} \quad \textbf{Ans.} ☜$$

Example 6.5 ***A hydraulic motor has a displacement of 150 cm³ and operates with a pressure of 85 bars and a speed of 1800 rpm. If the actual flow rate consumed by the motor is 5 Lps and the actual torque delivered by the motor is 185 N-m, find : (i) volumetric efficiency, (ii) mechanical efficiency, (iii) overall efficiency, and (iv) kW power delivered by the motor.***

Given Data : $V_D = 150\text{ cm}^3 = 150 \times 10^{-6}\text{ m}^3$; $P = 85\text{ bars} = 85 \times 10^5\text{ N/m}^2$;
$N = 1800\text{ rpm}$; $Q_A = 5\text{ Lps} = 5 \times 10^{-3}\text{ m}^3/\text{s}$; $T_A = 185\text{ N-m}$.

☺ ***Solution :*** First let us determine the theoretical flow rate.

$$Q_T = \frac{V_D \cdot N}{60} = \frac{(150 \times 10^{-6})(1800)}{60} = 4.5 \times 10^{-3}\ \text{m}^3/\text{s}$$

(i) To find the volumetric efficiency (η_{mech}) :

$$\eta_{vol} = \frac{Q_T}{Q_A} \times 100 = \frac{4.5 \times 10^{-3}}{5 \times 10^{-3}} = \mathbf{90\%} \quad \textbf{Ans.} ☜$$

(ii) To find the mechanical efficiency (η_{mech}) :

$$\eta_{mech} = \frac{T_A}{T_T} \times 100$$

where $$T_T = \frac{P\,V_D}{2\pi} = \frac{(85 \times 10^5)(150 \times 10^{-6})}{2\pi} = 202.92\ \text{N-m}$$

$$\therefore \quad \eta_{mech} = \frac{185}{202.92} \times 100 = \mathbf{91.17\%} \quad \textbf{Ans.} ☜$$

(iii) To find the overall efficiency (η_0) :

$$\eta_0 = \eta_{vol} \times \eta_{mech} = (0.90 \times 0.9117) \times 100 = \mathbf{82.05\%} \quad \textbf{Ans.} ☜$$

(iv) kW power delivered (i.e., actual power) by the motor :

$$\text{Actual power} = T_A\ (\text{N-m}) \times \omega\ (\text{rad/s})$$

$$= 185\left(\frac{2\pi \times 1800}{60}\right) = \mathbf{34{,}871\ W} \text{ or } \mathbf{34.87\ kW} \quad \textbf{Ans.} ☜$$

REVIEW AND SUMMARY

✓ *The **actuators** are the devices used for converting hydraulic energy into mechanical energy, and therefore have a function opposite to that of pumps.*

✓ ***Types of hydraulic actuators :*** *Based on the type of motion actuators produce, they are categorized into :*

1. *Linear actuators (also called 'hydraulic cylinders'), and*
2. *Rotary actuators (also called 'hydraulic motors')*
   - *(a) Continuous rotary actuators, and*
   - *(b) Limited rotation rotary actuators.*

✓ *The hydraulic actuators can be used for lifting, tilting, clamping, opening, closing, metering, mixing, turning, swinging, counter balancing, bending, and for many other operations.*

✓ *The **hydraulic cylinder** is a device that converts fluid power into linear mechanical force and motion.*

✓ *The important **types of hydraulic cylinders** are :*

1. *Single-acting cylinders,*
2. *Double-acting cylinders,*
3. *Telescopic cylinders,*
4. *Tandem cylinders,*
5. *Dual linear cylinders, and*
6. *Through rod cylinders.*

✓ *The construction, working, advantages, disadvantages, applications and ranges of the above-mentioned hydraulic cylinders have been discussed in this chapter.*

✓ ***The function of a rotary actuator** (also known as hydraulic motor) is to convert hydraulic energy into rotary mechanical energy.*

✓ *The hydraulic motors are very much identical in construction and size to rotary type pumps. They work on exactly the reverse principle to that of rotating pumps.*

✓ ***Types of hydraulic motors :*** *The hydraulic motors can be classified based on their degree of angular movement as :*

1. *Continuous rotary hydraulic motors, and*
   (a) Gear motors, (b) Vane motors, and (c) Piston motors.
2. *Limited rotation hydraulic motors.*
   (a) Vane type, and (b) Piston type.

✓ *In this chapter, the construction, working, advantages, disadvantages, applications, and ranges of the above-said hydraulic cylinders have also been presented in detail.*

✓ ***Formulae Summary :***

For double-acting cylinders :

$$\text{Cylinder extension force, } F_{ext}\,(N) = P_{ext}\,(N/m^2) \times A_p\,(m^2)$$

$$\text{Piston extension velocity, } v_{ext}\,(m/s) = Q_{in}\,(m^3/s) \,/\, A_p\,(m^2)$$

$$\begin{aligned}\text{Cylinder power for extension stroke, kW power} &= v_{ext}\,(m/s) \times F_{ext}\,(kN)\\ &= Q_{in}\,(m^3/s) \times P_{ext}\,(kN/m^2)\end{aligned}$$

$$\text{Cylinder retraction force, } F_{ret}\,(N) = P_{ret}\,(N/m^2) \times (A_p - A_r)\,(m^2)$$

$$\text{Piston retraction velocity, } v_{ret}\,(m/s) = Q_{in}\,(m^3/s) \,/\, (A_p - A_r)\,(m^2)$$

$$\begin{aligned}\text{Cylinder power for retraction stroke, kW power} &= v_{ret}\,(m/s) \times F_{ret}\,(kN)\\ &= Q_{in}\,(m^3/s) \times P_{ret}\,(kN/m^2)\end{aligned}$$

For single-vane type limited rotation motor :

$$\text{Hydraulic force acting on vane, } F = PA = P(R_V - R_R)\,L$$

$$\text{Torque capacity, } T = \frac{PL}{2}\,(R_V^2 - R_R^2)\,L = \frac{P \cdot V_D}{2\pi}$$

For hydraulic motors :

$$\text{Theoretical flow rate, } Q_T = \frac{V_D \times N}{60}$$

$$\text{Theoretical torque, } T_T = \frac{P \cdot V_D}{2\pi}$$

$$\text{Theoretical power} = T_T \times \omega$$

$$\text{Volumetric efficiency, } \eta_{vol} = \frac{Q_T}{Q_A} \times 100$$

$$\text{Mechanical efficiency, } \eta_{mech} = \frac{T_A}{T_T} \times 100$$

$$\begin{aligned}\text{Overall efficiency, } \eta_0 &= \eta_{vol} \times \eta_{mech}\\ &= \frac{T_A\,(N.m) \times \omega\,(rad/s)}{P\,(N/m^2) \times Q_A\,(m^3/s)} \times 100\end{aligned}$$

KEY TERMS ONE SHOULD REMEMBER

- **Actuators**
- **Hydraulic actuators**
- **Linear actuator**
- **Hydraulic cylinders**
  - **Single-acting cylinders**
  - **Double-acting cylinders**
  - **Differential cylinders**
  - **Telescopic cylinders**
  - **Tandem cylinders**
  - **Dual linear cylinders**
  - **Through rod cylinders**
  - **Double-rod cylinders**
- **Cylinder cushioning**
- **Rotary actuators**
- **Hydraulic motors**
- **Continuous rotary hydraulic motors**
  - **Gear motors**
  - **Vane motors**
  - **Piston motors**
  - **Axial-piston motors**
  - **Radial-piston motors**
- **Limited rotation hydraulic motors**
  - **Vane type**
  - **Piston type**
- **Hydraulic motor performance**
  - **Volumetric efficiency**
  - **Mechanical efficiency**
  - **Overall efficiency**
  - **Hydraulic power**
  - **Brake power**
- **Hydraulic motor performance curves**
- **Fluid transmission device**

REVIEW QUESTIONS

Short Answer Type Questions

On Hydraulic Cylinders

1. What is the function of a hydraulic actuator ?
2. How can you classify the hydraulic actuators ?
3. What is the function of a hydraulic cylinder ?
4. Name different types of hydraulic cylinders.
5. Mention few applications of hydraulic cylinders.
6. By what means, single-acting cylinders are retracted ?
7. Differentiate between a single acting and a double-acting hydraulic cylinder.
8. Why are double-acting cylinders preferred over single-acting cylinders in many hydraulic applications ?
9. Why are double-acting cylinders known as differential cylinders ?
10. What is meant by cylinder cushioning ?
11. What is the purpose of a cylinder cushion ?
12. What is a telescopic cylinder ? When do you use it ?
13. What are tandem cylinders ? When are they normally used ?
14. What do you mean by double-rod cylinders ?
15. Name the different cylinder mountings.

On Hydraulic Motors

16. What is the function of a hydraulic motor ? How does it differ from a hydraulic cylinder ?
17. Name the basic types of rotary actuators. Which will provide the maximum degree of rotation ?
18. How do you rate/specify a hydraulic motor ?
19. Name different types of continuous rotary hydraulic motors.
20. Differentiate between hydraulic motors and hydraulic pumps.
21. What are the advantages and disadvantages of gear motors ?
22. Why are vane motors always fixed displacement units ?
23. Which hydraulic motor is generally the most efficient ? Why ?
24. Mention few applications where piston motors are employed.
25. What do you mean by a limited rotation hydraulic motor ?
26. Mention few applications of limited rotation hydraulic motors.
27. With respect to hydraulic motors, define the terms volumetric, mechanical, and overall efficiency.

Essay Answer Type Questions

On Hydraulic Cylinders

1. With a neat sketch, explain the construction and operation of a double-acting hydraulic actuator. Also derive an expression for the torque capacity of the cylinder.
2. With a neat sketch, explain the 'end cushion' provided in hydraulic cylinders.
3. Explain with neat sketch the principle of operation of telescopic cylinder.
4. Write short notes on the following linear actuators :

   (*a*) Tandem actuators, and (*b*) Double-rod cylinders.

On Hydraulic Motors

5. With a neat sketch, explain how torque is developed in a gear motor ?
6. With a neat sketch, explain the construction, operation, advantages, limitations, and applications of a vane pump ?
7. Explain how an axial type piston motor differ in operation from a radial type piston motor. Also bring out the advantages, disadvantages, and ranges of a piston motor.
8. What is meant by a limited rotation hydraulic actuator ? Explain the operation of any one limited rotation hydraulic motor.

PROBLEMS FOR PRACTICE

On Hydraulic Cylinders

1. A pump supplies liquid at 84 Lpm to a 45 mm diameter double-acting hydraulic cylinder. If the load is 4750 N (extending and retracting) and the piston rod diameter is 22 mm, find

   (*i*) Hydraulic pressure for the extension and retraction strokes.

   (*ii*) Piston velocity for the extension and retraction strokes.

   (*iii*) Cylinder kW power during the extension and retraction strokes.

[***Ans.*** (*i*) 29.88 bars and 39.25 bars ; (*ii*) 0.88 m/s and 1.16 m/s ; (*iii*) 4.18 kW and 5.51 kW]

On Hydraulic Motors

2. A single-vane hydraulic motor has the following specifications :

   Outer radius of rotor = 14 mm; Outer radius of vane = 40 mm; Width of vane = 25 mm

   If the torque load is 120 N-m, what pressure must be developed to overcome the load ?

   [***Ans.*** 68.37 bars]

3. What torque would a hydraulic motor deliver at a speed of 2000 rpm if it produces a brake power of 5 kW.

   [***Hint :*** *Use brake power* $= \dfrac{2\pi NT}{60}$] [***Ans.*** 23.87 N-m]

4. A hydraulic motor has a 0.15 litres volumetric displacement. If it has a pressure rating of 75 bars and it receives oil from a 6 Lps theoretical flow rate pump, find :

   (*i*) Motor speed, (*ii*) Motor theoretical torque, and (*iii*) Motor theoretical power.

   [***Ans.*** (*i*) 2400 rpm; (*ii*) 179 N-m ; (*iii*) 45 kW]

5. A hydraulic motor has a displacement of 80 cm^3 and operates with a pressure of 70 bars and a speed of 500 rpm. If the actual flow rate consumed by the motor is 0.0007 m^3/s and the actual torque delivered by the motor is 80 N-m, find : (*i*) volumetric efficiency, (*ii*) mechanical efficiency, (*iii*) overall efficiency, and (*iv*) the actual kW delivered by the motor.

   [***Ans.*** (*i*) 95.24%; (*ii*) 89.76%; (*iii*) 85.5%; (*iv*) 4.19 kW]

□□

Unit

3

Design of Hydraulic Circuits

Chapter 7 : Hydraulic Valves : The Regulator

Chapter 8 : Accumulators and Intensifiers

Chapter 9 : Electrical Controls for Fluid Power Systems

ENGINEERING Apprise Education, Reprise Innovations

Chapter 7

Hydraulic Valves: The Regulator

> *"Nothing has such power to broaden the mind as the ability to investigate systematically and truly all that comes under thy observation in life."*
>
> ***– Marcus Aurelius***

> *"Science is simply common sense at its best, that is, rigidly accurate in observation and merciless to fallacy in logic."*
>
> ***– Thomas H. Haxley***

> *"The butterfly counts not months but moments, and has time enough."*
>
> ***– Rabindranath Tagore***

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Identify, understand, and appreciate the various control valves required for proper functioning of the hydraulic systems.

☑ Describe the purpose, construction, and operation of three types of valve configurations—poppet valves, sliding spool valves, and rotating spool valves.

☑ Understand and explain the construction, operation, and application of various directional control valves (such as check valves, position valves, and shuttle valves).

☑ Learn how the graphic symbols are designated for various hydraulic valves.

☑ Distinguish between 2/2, 3/2, 4/2, and 4/3 directional control valves.

☑ Understand and explain the construction, operation, and application of various pressure, control valves (such as pressure relief valves, pressure reducing valves, and sequence valves).

☑ Understand and explain the construction, operation, and application of various flow control valves (such as globe valves, needle valves, pressure-compensated flow control valves).

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CHAPTER

7 HYDRAULIC VALVES : THE REGULATOR

7.1. INTRODUCTION

So far, we have discussed about hydraulic pumps for generating pressure, and about hydraulic cylinders and motors for converting that pressure into useful mechanical work. But to direct and regulate the pressure and the flow of the fluid from the pump to the actuators, all the hydraulic (as well as pneumatic) systems require control valves. In fact, the efficient function of the entire fluid power systems depend to some extent on the control components (*i.e.*, valves) used. Although there are significant practical differences between the hydraulic and pneumatic devices (mainly in terms of operating pressures and types of seals), the operating principles and descriptions of control valves are very similar.

In this chapter, we shall discuss about the various control valves required for proper functioning of the hydraulic systems.

7.1.1. What are Hydraulic Valves ?

- ✓ *Hydraulic valves are devices used to control pressure, flow direction, or flow rate in hydraulic circuits.*
- ✓ These control valves utilize mechanical motion to control the distribution of hydraulic energy within the system.

7.1.2. Types of Control Valves

Control valves are classified into three basic types, based on their function in the hydraulic system, as :

1. Directional control valves,
2. Pressure control valves, and
3. Flow control (or volume control) valves.

7.2. VALVES CONFIGURATION

There are three essential types of control valves based on their configuration or modes of operation. They are :

1. Poppet (or seat) valves,
2. Sliding spool valves, and
3. Rotary spool valves.

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A brief understanding of these valve configurations are essential before discussing the construction and operation of different types of control valves.

7.3. POPPET (OR SEAT) VALVES

7.3.1. Construction and Operation

The most common form of poppet valve is shown in Fig.7.1. Normally this valve is in the closed condition and hence there is no connection between port 1 and port 2. In poppet valves, balls, discs or cones are used in conjunction with valve seats to control the flow. In the Fig.7.1, a ball is shown.

When the push-button is depressed, the ball is pushed out of its seats and hence the flow is permitted from port 1 to port 2. When the push-button is released, spring and fluid pressure force the ball back up against its seat and so closes off the flow.

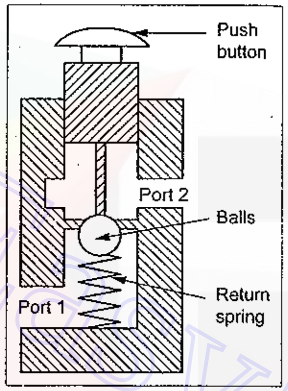


Fig. 7.1. Construction of a poppet valve

7.3.2. Advantages of Poppet Valves

Poppet valves exhibit the following advantages :

(*i*) Simple in design,	(*ii*) Less expensive,
(*iii*) Very robust, and	(*iv*) Less sensitive to fluid contamination.

7.3.3. Disadvantages of Poppet Valves

The force required to operate the poppet valves are more. Therefore they are suitable mostly for low pressure applications.

7.3.4. Applications of Poppet Valves

Poppet valves are essentially two-way valves. Therefore they are limited to :

(*i*) applications in which flow reversal is not required, *e.g.*, check valves and relief valves, and

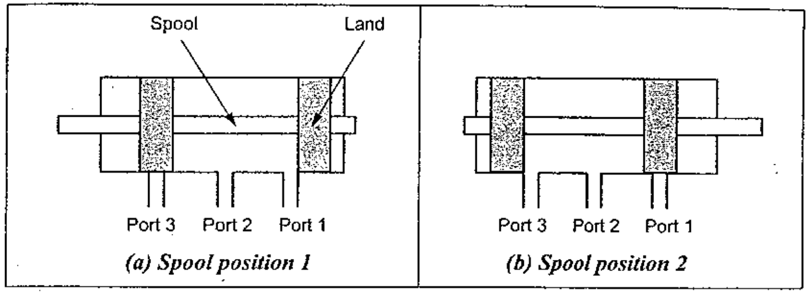
(*ii*) low-power applications because of their relatively high leakage rates.

7.4. SLIDING-SPOOL VALVES

The sliding-spool valves are the most frequently used type in hydraulic systems.

7.4.1. Construction and Operation

Fig.7.2 illustrate a typical sliding spool valve. A spool moves horizontally within the valve body to control the flow. The raised areas called 'lands' block or open port to give the required operation.



(a) Spool position 1 *(b) Spool position 2*

Fig. 7.2. Construction and operation of a sliding-spool valve

In Fig.7.2(*a*), the fluid supply is connected to port 1 and now port 3 is in closed position. Thus the flow is permitted from port 1 to port 2. In Fig.7.2(*b*), when the spool is moved to the left, the fluid supply is cut off and port 2 is connected to port 3. Thus the flow is permitted from port 2 to port 3.

7.4.2. Advantages of Sliding-Spool Valves

(*i*) Different operations can be achieved with a common body and different spool.

(*ii*) Reduced manufacturing cost.

(*iii*) Reduced fluid leakage rate.

(*iv*) All types of actuation are easily adaptable.

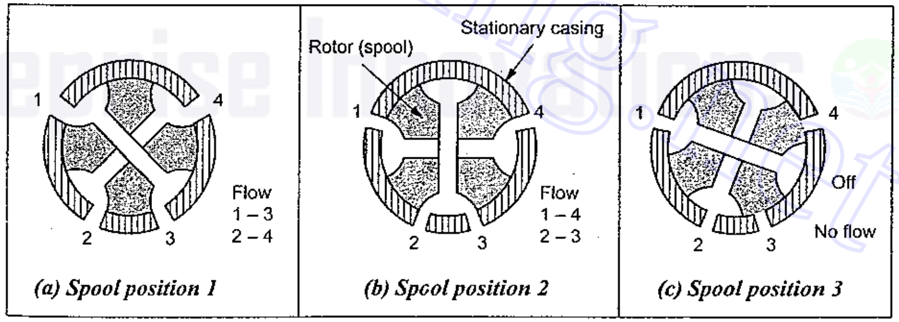
7.4.3. Applications of Sliding-Spool Valves

They are used for high pressure applications.

7.5. ROTARY SPOOL VALVES

Rotary spool valves have a rotating spool which aligns with holes in the valve casing to give the required operation.

7.5.1. Construction and Operation



(a) Spool position 1 *(b) Spool position 2* *(c) Spool position 3*

Fig. 7.3. Construction and operation of a rotary-spool valve

Fig.7.3 illustrates the construction and operation of a typical rotary spool valve, with centre off action. When the spool rotates, it opens and closes ports and subsequently allows and prevents the fluid flow through that ports.

In Fig.7.3, there are four ports 1, 2, 3, and 4. For the position of spool as in Fig.7.3(*a*), the flow is permitted from port 1 to port 3, and from port 2 to port 4. When the spool rotates to a position as shown in Fig.7.3(*b*), the flow is permitted from port 1 to port 4, and from port 2 to port 3. For the spool position shown in Fig.7.3(*c*), there is no fluid flow as all the four ports are blocked.

7.5.2. Advantages of Rotating Spool Valves

(*i*) They are simple and compact in design and operation.

(*ii*) They have low operating forces.

7.5.3. Applications of Rotating Spool Valves

The rotary spool valves are widely used for low pressure applications.

7.6. DIRECTIONAL CONTROL VALVES

7.6.1. What are Directional Control Valves ?

✓ As the name suggests, the function of a directional control valve (DCV) is to control the direction of flow in a hydraulic circuit.

✓ In other words, *directional control valves (DCVs) regulate the direction in which the fluid flows in a hydraulic circuit.*

✓ In addition to controlling direction of actuator motion, the directional valves are also used (*i*) to select alternate control circuits, and (*ii*) to perform logic control functions.

✓ These valves are not intended to change the rate of flow of fluid; but they are either completely open or completely closed. They can be actuated to switch the fluid flow direction by various actuating means such as electrical, mechanical or fluid pressure signals. This results in corresponding connection or disruption of flow between various port openings.

7.6.2. Classification of Directional Control Valves

The directional control valves can be classified in many different ways.

I. The directional control valves are basically classified, ***according to the construction,*** into three groups, as :

1. Poppet (or seat) valves,
2. Sliding spool valves, and
3. Rotary spool valves.

II. ***Based on the number of ports***[†] ***present,*** the directional control valves may be classified as :

(*i*) Two way valves,
(*ii*) Three way valves, and
(*iii*) Four way valves.

III. ***Based on the mode of actuation,*** the directional control valves can be classified as :

(*i*) Manually operated directional valves,
(*ii*) Mechanically operated directional valves,
(*iii*) Solenoid operated directional valves, and
(*iv*) Pilot operated directional valves.

IV. However, for our study we can classify the directional control valves into three :

1. Check valves,
2. Position valves, and
3. Shuttle valves.

Now, we shall discuss the construction and operation of some of the important directional control valves, in the following sections.

7.7. CHECK VALVES (OR TWO WAY VALVES)

7.7.1. Introduction

✓ Check valves are the most commonly used and the simplest type of directional control valves.

✓ The check valve is a ***two-way valve*** because it contains two ports. Also *a check valve is analogous to a diode in electric circuits.*

✓ ***Functions :*** The check valves are used :

(*i*) to allow free flow in only one direction, and

(*ii*) to prevent any flow in the other direction.

✓ Since check valves block the reverse flow of the fluid, they are also known as ***non-return valves.***

✓ The symbolic representation of a check valve, shown in Fig.7.4, illustrates its function clearly.

7.7.2. Types of Check Valves

Check valves are of several types. But the two important types of check valves are :

1. Poppet-type check valves, and
2. Pilot-operated type check valves.

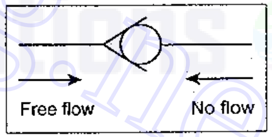


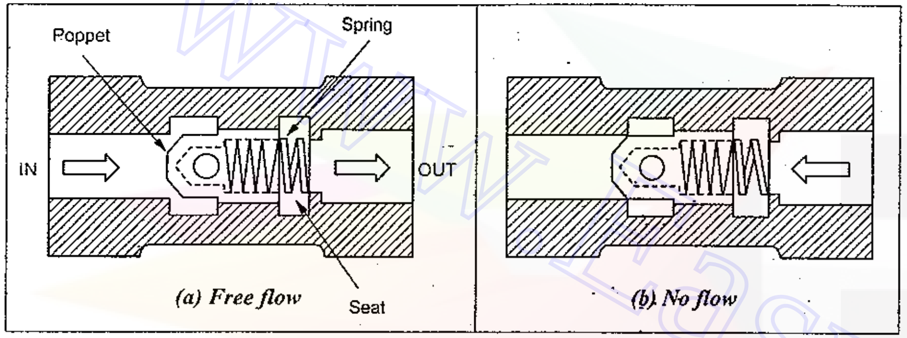
Fig. 7.4. Symbolic representation of a check valve

[†] 'Ports' or 'Ways' are nothing but openings present in a control valve. They refer flow path through the valve.

7.7.3. Poppet-Type (or Simple) Check Valves

7.7.3.1. Construction and Operation

The construction and operation of a typical poppet type check valve is illustrated in Fig.7.5. Normally a spring holds the poppet in the closed position.



(a) Free flow (b) No flow

Fig. 7.5. Construction and operation of a poppet-type check valve

When flow is in the normal direction, the liquid pressure acts against the spring tension to hold the poppet offset the seat. When the liquid pressure overcomes the spring force, as shown in Fig.7.5(*a*), the valve allows the free flow. When flow stops, the spring seats the poppet and liquid cannot pass in the reverse direction.

Instead, if flow is attempted in the opposite direction as shown in Fig.7.5(*b*), the liquid pressure along with the spring force pushes the poppet in the closed position. Hence no flow is permitted in opposite direction.

7.7.3.2. Applications of Simple Check Valves

Usually poppet type check valves are used to provide the pilot pressure to operate larger valves.

7.7.4. Pilot-Operated Check Valves

The piloted operated check valve allows free fluid flow in one direction, but reversed flow depends upon the pilot actuation. That means, this type check valve also allows the reverse flow, provided pilot pressure is applied at the pilot pressure port of the valve to overcome the spring force of the poppet.

7.7.4.1. Construction and Operation

The construction and operation of a typical pilot-operated check valve is illustrated in Fig.7.6.

First, the free flow in the normal direction from port A to port B is achieved in the usual manner. But the reverse flow is blocked as the fluid pressure pushes the poppet into the closed position.

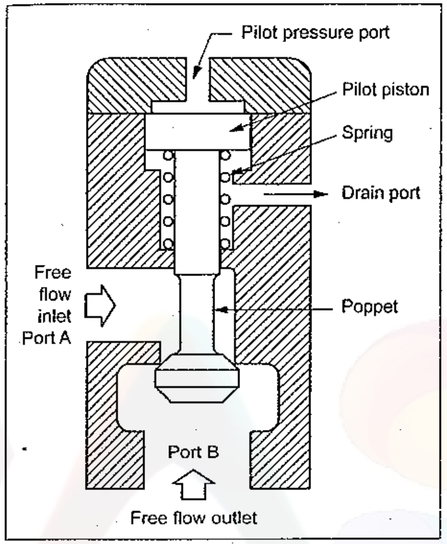


Fig. 7.6. Pilot-operated check valve

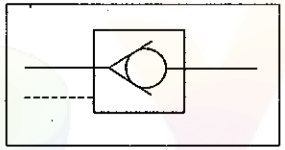


Fig. 7.7. Symbolic representation of a pilot-operated check valve

In order to permit the fluid flow in the reverse direction *i.e.*, from port B to port A, a pilot pressure is applied through the pilot pressure port. The pilot pressure pushes the pilot piston and the poppet down. Thus the fluid flow in the reverse direction is also obtained. The purpose of the drain port in the circuit is to prevent oil from creating a pressure buildup on the bottom of the pilot piston.

7.7.4.2. Graphical Symbol

Fig.7.7 shows the symbolic representation of a pilot-operated check valve. In Fig.7.7, the dashed line presents the pilot pressure line.

7.7.4.3. Applications of Pilot-Operated Check Valves

The pilot-operated check valves are widely used to hydraulically lock the cylinders such as in a hydraulic jack.

7.8. POSITION VALVES

7.8.1. Introduction

- ✓ *The function of the position valve is to control the introduction of fluid to the lines of the system.* When the valve is operated, the liquid lines within it are shifted.
- ✓ The position valves are usually described by the following relation :

(Number of ports/Number of positions) valve.

For example, a 4/2 valve has 4 ports and 2 positions.

- ✓ The ports of a directional control valve are designated by letters, as listed in Table 7.1.

Table 7.1. Ports' designations

Ports	Designation
Working lines	A, B, C, and so on.
Pressure (power) supply	P
Return/Exhaust lines	R, S, T and so on. (Normally T for hydraulic systems, R and S for pneumatic systems.)
Control (pilot) lines	Z, Y, X, and so on.

7.8.2. Valve Position

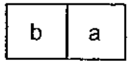
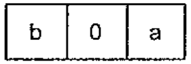
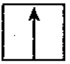
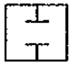
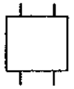
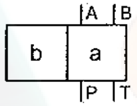
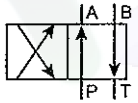
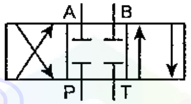
- ✓ A direct control valve has two or three working positions generally. They are :
  1. Normal or zero position or neutral position.
  2. Working positions (such as retract and extend positions).
- ✓ It is necessary to differentiate between neutral and operating positions. In directional control valves with spring return, the neutral position is defined as the position to which the valve returns after the actuating force has been withdrawn.
- ✓ In all fluid control systems, the valve positions can be represented by letters *a*, *b*, *c*, and so on, with '0' being used for central neutral position.
- ✓ The starting (or initial) position is the position taken up by the valve (due to spring in case of spring actuated directional control valve) after installation. The valve attains the working positions when actuated.

7.8.3. Valve Symbols

For representing valves in circuit diagrams, symbols are used. Generally a valve is represented by a square for each of its switching positions. Two positions are represented by two adjacent squares. It should be noted that symbols show only the functional aspect of the valve and not its principle of design or constructional details.

The basic valve symbols and their description are presented in Table 7.2.

Table 7.2. Basic valve symbols and their description

	Valve symbol	Description
Valve position		A valve position is represented by a square.
Two position valve		A number of squares is equal to the number of distinct positions that the valve can take up. Therefore the figure shows the two position valve.
Three position valve.		Three adjacent squares indicate the three position valve.
Flow path		Inside a square, the line indicates the flow and the arrow the direction of flow.
Flow shut off		Cut-offs of fluid flow are shown by short transverse lines inside the square.
Initial convections		The ports of a valve are added on the outside of the square box. The connections to inlet and outlet ports are drawn only to a initial (or neutral) position.
4/2 valve		Figure shows the 4 ports (A, B, P and T) and 2 positions (*a* and *b*) valve.
4/2 valve		In position '*a*', the fluid is delivered from port P to port A and returned from port B to port T. In position '*b*', flow is reversed, *i.e.*, the fluid is delivered from port P to port B and returned from port A to port T. [*Note :* Here ports are drawn only to the initial position. For the other position, readers should mentally identify the ports.]
4/3 valve		Figure shows a 4 ports and 3 positions valve. In position '*a*', the fluid is delivered from port P to port A and returned from port B to port T. In position '0', the load is in the off (or neutral) position. Since all A, B, P and T ports are blocked, therefore no fluid flow. In position '*b*', the flow is reversed. [*Note :* Here ports are shown only to the neutral position; for other two positions, readers should mentally identify the ports.]

Note The above valve symbols are to be used in hydraulic circuits. The corresponding symbols having unfilled arrow heads can be used in pneumatic circuits.

7.8.4. Valve Actuation Symbols

To obtain complete valve symbols, valve actuations[†] symbols must be combined with the above basic valve symbols. Fig.7.8 shows symbols for the various ways in which the valves can be actuated.

[†] Actuation is a method of moving valve element from one position to another.

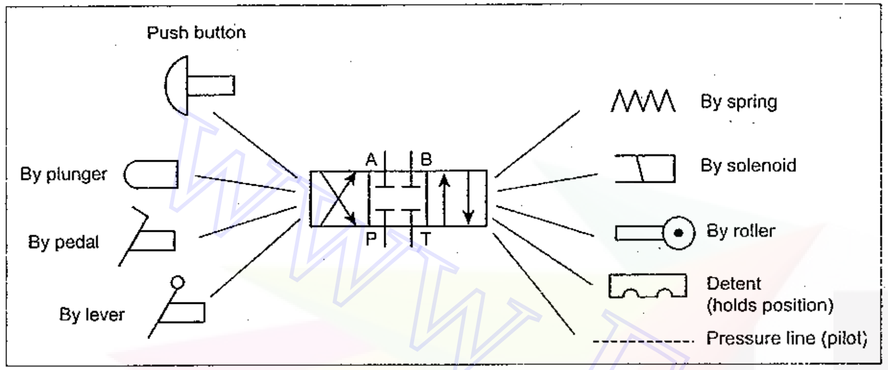
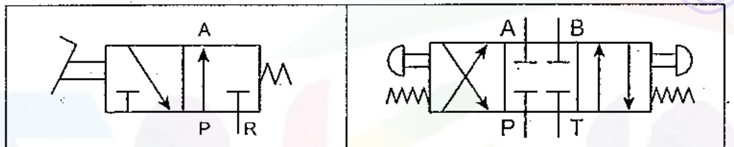


Fig. 7.8. Actuation symbols

7.8.5. Complete Graphic Valve Symbols

Fig.7.9 illustrates how these various symbols can be combined to describe a complete valve operation. Fig.7.9(a) represents a pedal actuated, spring return 3/2 valve.

Fig.7.9(b) represents push-button operated, spring return, 4/3 valve.



(a) 3/2 valve, pedal actuated, spring return to centre

(b) 4/3 valve, push button operated, spring return to centre

Fig. 7.9.

7.8.6. Valve Actuation

✓ In order to respond to the system requirements, we must provide a means of actuation to the hydraulic control valves.

✓ For example, to move the spool in a position valve, to change the setting of a pressure control valve, or to adjust flow-control valves, we need some form of actuation.

✓ ***Types of actuation methods :*** The four actuation methods normally used are :

1. Manual actuation,
2. Mechanical actuation,
3. Electrical actuation, and
4. Fluid actuation.

✓ The graphic symbols for various actuation devices are shown already in Fig.7.8.

1. Manual Actuation

✓ Manual actuation requires action by an operator who must make a control judgement based upon some system requirement.

✓ Manual actuators include levers, push buttons, and pedals.

✓ Manual actuation is commonly used when system requirement is not critical.

✓ It is widely used in machine tools and mobile equipment.

2. Mechanical Actuation

✓ Mechanical actuators include springs, plungers, rollers, cams, and mechanical linkages.

✓ The springs and plungers are most commonly used to provide force for a variety of valve operations.

3. Electrical Actuation

✓ Electrical actuators are nothing but solenoid actuators.

✓ A solenoid is a electromagnetic coil. When it is energized, it creates a magnetic force that pulls the armature. The armature is connected to the spool of the valve and the valve is actuated.

✓ Most applications use 115 V, 60 cps solenoids. Also they are available in a wide range of AC or DC voltages. DC solenoids are quiet in operation, whereas AC solenoids may hum or chatter.

✓ The solenoids are energized by signals from pressure switches, limit switches, or timers which usually operate through power or signal relays to accommodate the current required to actuate the solenoid.

✓ Solenoid actuation provides flexibility in hydraulic system design. System commands can be obtained from signals in any port of the circuit.

4. Pilot Fluid Actuation

✓ Oil or air can be used to provide fluid power for the actuation of valves.

✓ Air can be used to activate single-stage valves, or pilot valves on multistage units.

✓ The advantage of pilot-fluid actuation is the long life of fluid components compared to that of electrical components.

7.8.7. Classification of Position Valves

Position valves are classified in terms of the number of fluid ports and the number of valve positions, as :

(*i*) Two way, two position valves (2/2 valves).
(*ii*) Three way, two position valves (3/2 valves).
(*iii*) Four way, two position valves (4/2 valves),
(*iv*) Four way, three position valves (4/3 valves), and so on.

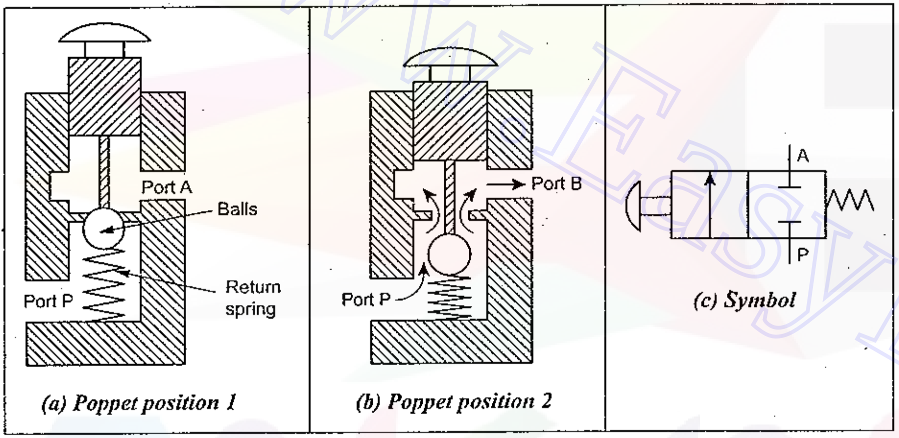
7.9. TWO POSITION VALVES

7.9.1. 2/2 Directional Control Valves

The 2/2 valves have 2 ports and 2 positions.

7.9.1.1. Construction and Operation

The poppet-type check valve illustrated in Fig.7.10 is a typical 2/2 valve. However, the construction and operation of a similar type 2/2 DC valve is illustrated in Fig.7.1.



(a) Poppet position 1 *(b) Poppet position 2* *(c) Symbol*

Fig. 7.10. Operation of a 2/2 DC valve

Position 1 : When the push-button is in normal position, spring and fluid pressure force the ball up, therefore the flow is blocked, as shown in Fig.7.10(*a*).

Position 2 : When the pressure of the push-button pushes the ball off its seat, then the flow is permitted from port P to port A, as shown in Fig.7.10(*b*).

7.9.1.2. Graphic Symbols

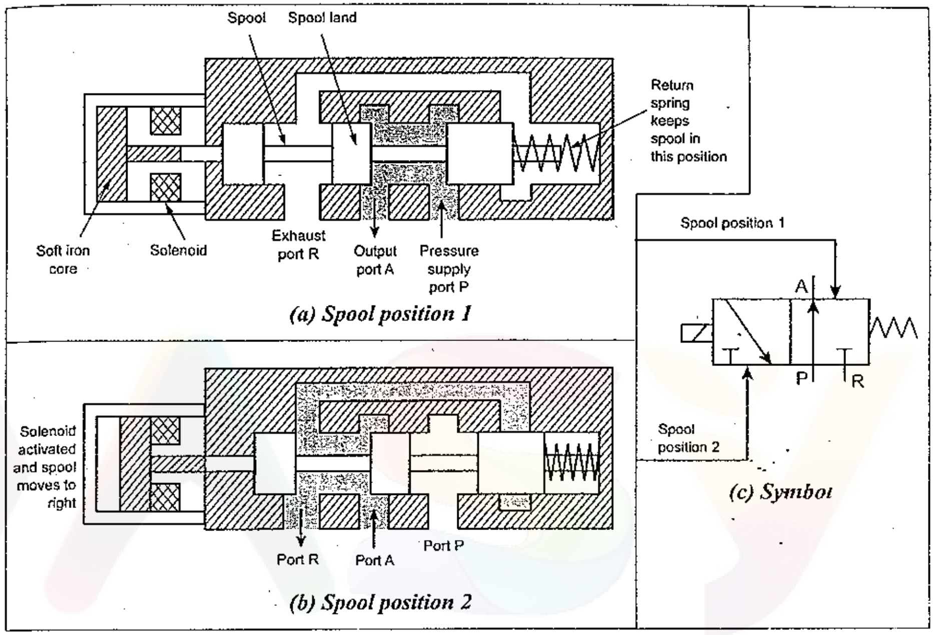
Fig.7.10(*c*) depicts the above operation of a push-button operated, spring return type 2/2 valve.

7.9.2. 3/2 Directional Control Valves

The 3/2 valves have 3 ports and 2 positions.

7.9.2.1. Construction and Operation

The construction and operation of a typical sliding-spool type, solenoid-actuated 3/2 DC valve is illustrated in Fig.7.11. It has three ports or openings : pressure supply port (P), output port (A), and exhaust port (R).



(a) Spool position 1 *(b) Spool position 2* *(c) Symbol*

Fig. 7.11. Construction and operation of a solenoid-actuated 3/2 vane

As shown in Fig.7.11(*a*) and (*b*), the valve is actuated by a current passing through a solenoid and, returned to its original position by a spring. The spool slides over the finely finished valve bore inside the valve housing.

Spool position 1 : In the original or neutral position of the spool, (Fig.7.11(*a*)), the pressurized fluid flows from port P to port A to move the actuator, the exhaust port (R) remaining closed.

Spool position 2 : When the solenoid is activated (Fig.7.11(*b*)), the spool moves to the extreme left. In the extreme spool position, the fluid from port P gets closed and hence the fluid is permitted to flow from port A to port R.

Thus the valve alternately connects and disconnects fluid supply to the cylinder by the sliding spool.

7.9.2.2. Graphic Symbol

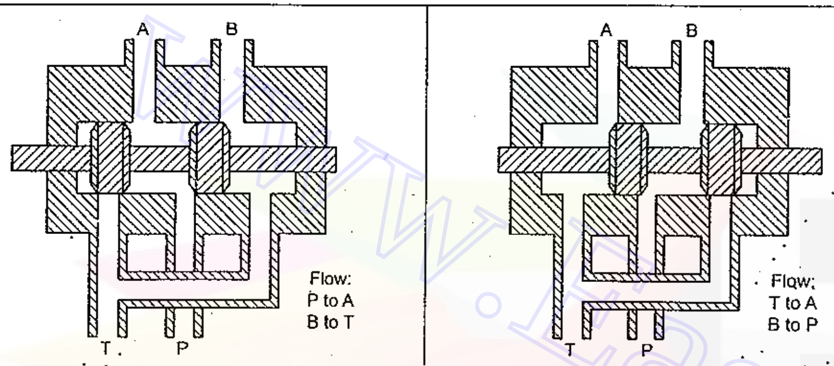
Fig.7.11(*c*) shows a graphic symbol of a solenoid actuated, spring return 3/2 valve, illustrating the above operation.

7.9.3. 4/2 Directional Control Valves

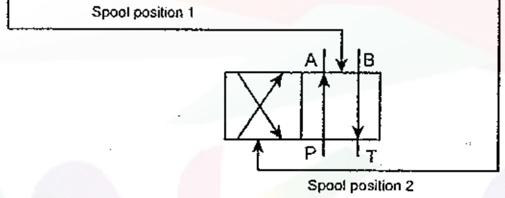
The 4/2 valves have 4 ports and 2 distinct positions.

7.9.3.1. Construction and Operation

The construction and operation of a typical sliding-spool type 4/2 DC valve is illustrated in Fig.7.12. It has four ports or openings, P, A, B, and T.



(a) Spool position 1 *(b) Spool position 2*



(c) Symbol of 4/2 valve

Fig. 7.12. Operation of a 4/2 DC valve

Spool position 1 : When the spool is in position as shown in Fig.7.12(*a*), the fluid can flow from port P to port A and return from port B to port T.

Spool position 2 : When the spool is in the position as shown in Fig.7.12(*b*), the fluid can flow from port T to port A and return from port B to port P.

7.9.3.2. Graphic Symbol

Fig.7.12(*c*) represents the graphic symbol for the above 4/2 DC valve.

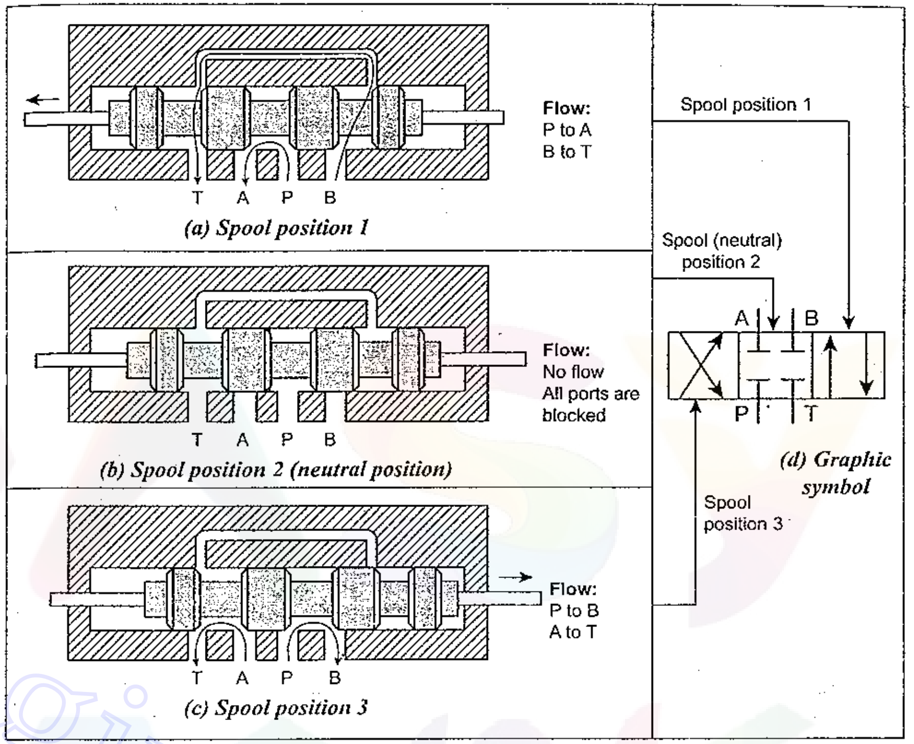
7.10. THREE POSITION VALVES

7.10.1. 4/3 Directional Control Valves

The 4/3 valves have 4 ports and 3 distinct positions.

7.10.1.1. Construction and Operation

The construction and operation of a typical sliding-spool type 4/3 DC valve is illustrated in Fig.7.13. This valve also has four ports P, A, B, and T.



(a) Spool position 1

(b) Spool position 2 (neutral position)

(c) Spool position 3

(d) Graphic symbol

Fig. 7.13. Operation of a 4/3 DC valve

Spool position 1 : For the spool position shown in Fig.7.13(*a*), the fluid can flow from port P to port A and return from port B to port T.

Spool position 2 : During the neutral position shown in Fig.7.13(*b*), all the ports are blocked.

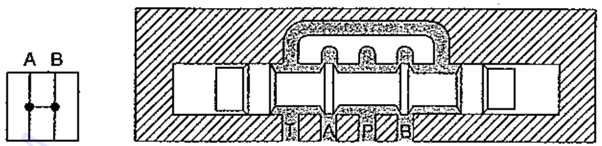
Spool position 3 : For the spool position shown in Fig.7.13(*c*), the reverse flow is permitted. *i.e.*, fluid can flow from port P to port B and return from port A to port T.

7.10.1.2. Graphic Symbol

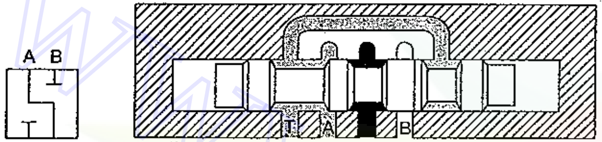
Fig.7.13(*d*) represents the graphic symbol for the above 4/3 DC valve.

7.10.2. Centre Flow Configurations for Three-Position, Four-Way Valves

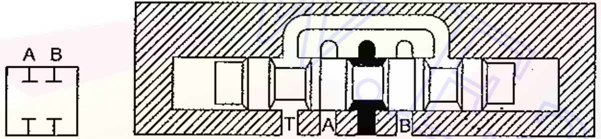
As we discussed, the two extreme positions of a 4/2 control valve controls the two extreme direction of motion of fluid. In 4/3 valves, the third position usually is an intermediate or a centre position. Varieties of centre positions are possible in 4/3 DC valves by suitably designing the spool. Fig.7.14 illustrates some of the widely used centre flow path configurations for 4/3 valves.



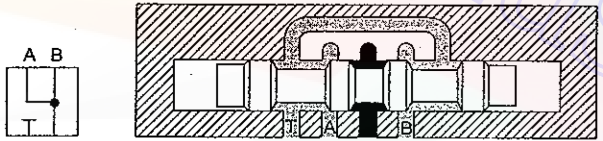
(a) Open center



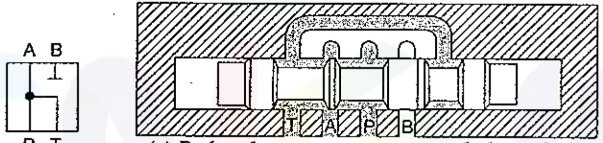
(b) Pressure and B closed; A open to tank



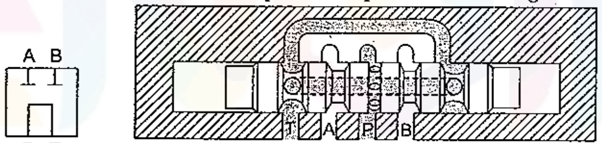
(c) Closed center – All ports closed



(d) Pressure closed; A & B open to tank



(e) B closed; pressure open to tank through A



(f) Tandem centre

Fig. 7.14. Various center flow paths for the three-position, four-way valves

These centre positions are briefed below :

1. Open Centre : ✓ In open centre type, all ports of the valve P, A, B, and T are open to each other, as shown in Fig.7.14(*a*).

✓ *Advantage :* As soon as the cylinder completes its cycle, the open centre DC valve allows the pump flow to return to back the tank (reservoir) at a minimum pressure. This prevents unnecessary heat build-up in the system.

✓ *Disadvantage :* When the valve is centred, no other cylinder can operate. Therefore, open-centre type valve is used mostly for a single cylinder or single motor circuit.

2. Closed Centre : ✓ In closed centre type, all the ports P, A, B, and T are blocked to each other, as shown in Fig.7.14(*c*).

✓ *Advantage :* The closed centre type valve can use the pump flow for other parts of the circuit. Therefore closed typed valves are used when multiple functions are to be accomplished from one source.

✓ *Disadvantage :* When the valve is in closed centre position, the pump flow cannot be unloaded to the tank. So the hydraulic cylinder or fluid motor cannot be moved.

3. Tandem Centre : ✓ The tandem centre type valve, as shown in Fig.7.14(*f*), directs the pump flow out of the reservoir port T with the other two working ports A and B closed when in the centre position.

✓ *Advantage :* Like open centre valve, this type valve also unloads the pump at essentially atmospheric pressure. The application of this design is to permit the flow to be connected to a series of valves for multiple circuits.

✓ *Disadvantage :* When a number of cylinders are operated from a single source, the pressure differential for each tandem centre valve will be 3 to 4 bar each while the valve is in its centre position.

4. Floated Centre : ✓The floated centre type valves allow independent operation of cylinders connected to the same power source, as shown in Fig.7.14(*b*), (*d*), and (*e*).

✓ *Advantage :* This type does not build up any pressure in the cylinder lines. Therefore, there will not be any drifting of cylinders during this condition.

✓ *Disadvantage :* The load cannot be locked in this position during the neutral position.

7.10.3. Applications of Position Valves

✓ ***Two way directional valves*** are generally used as shut off valves. Unlike a check valve, the two-way valve can block flow in both directions.

✓ Generally ***three way directional control valves*** are used to control single-acting linear actuators.

✓ The ***four way directional control valves*** are used to control double-acting actuators.

✓ A ***three-position valve*** can be used : (*i*) to isolate an actuator from the circuit, (*ii*) to provide a bypass to the reservoir around the actuator, or (*iii*) to hold an actuator in an intermediate position.

7.10.4. Specification of Directional Control Valves

The DC valves are usually specified by the following parameters :

1. Rated flow,
2. Rated pressure,
3. Outlet and inlet port size,
4. 3 way or 4 way spool,
5. Open or closed centre application,
6. Spring centred or not,
7. Solenoid type and power, *etc.*

7.11. SHUTTLE VALVE

7.11.1. What are Shuttle Valves ?

- ✓ Shuttle valve is also a typical directional control valve.
- ✓ *Shuttle valves, also known as **double check valves**, are used when control is required from more than one power source.*
- ✓ In other words, a shuttle valve allows pressure in a line to be obtained from alternative sources.
- ✓ Shuttle valve is generally used to shift the fluid flow from the secondary backup pump (source), when the main pump (source) becomes inoperate.

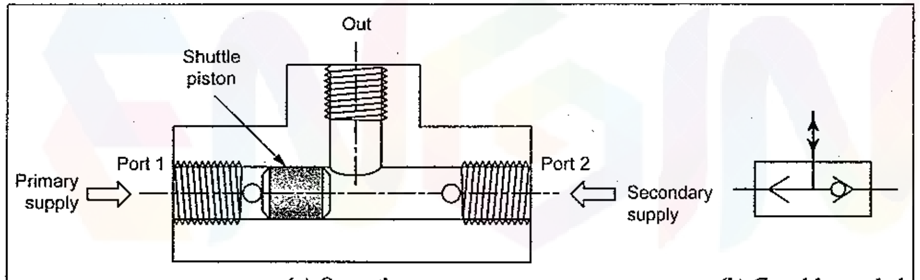
7.11.2. Construction and Operation

The construction and operation of a typical three-port shuttle valve is illustrated in Fig.7.15(*a*). This shuttle valve provides a fluid path for two alternate sources.

As long as pressure in the right inlet port is greater than in the left, the shuttle piston closes the left port. When pressure at the left port becomes greater than at the right, the piston moves to the right against a stop, closing the right port and opening the left.

7.11.3. Graphic Symbol

Fig.7.15(*b*) shows the graphic symbol of a shuttle valve.



(a) Operation ***(b) Graphic symbol***

Fig. 7.15. Shuttle valve

7.12. PRESSURE-CONTROL VALVES

7.12.1. What are Pressure Control Valves ?

- ✓ As the name suggests, *pressure control valves are the devices used to control the fluid pressure in a system.*
- ✓ ***Functions :*** The pressure control valves perform one or more of the following functions :

(*i*) To limit the maximum pressure in various circuit components as a safety measure.

(*ii*) To maintain the desired pressure levels in various parts of the circuits.

(*iii*) To unload system pressure, *i.e.*, to change the direction of all or part of the flow when the pressure at a certain point reaches a specified level.

(*iv*) To assist sequential operation of actuators in a circuit with pressure control.

7.12.2. Types of Pressure Control Valves

The important types of pressure control valves and their functions are presented in Table 7.3.

Table 7.3. Types of pressure control valves and their functions

Sl.No.	Type	Function/Description
1.	Pressure limiting valve (relief valve)	Relief valve limits the maximum pressure that can be applied to the part of the system to which it is connected.
2.	Pressure reducing valve (pressure-regulator valve)	Pressure reducing valve maintains a prescribed reduced pressure at its outlet regardless of the valve inlet pressure.
3.	Sequence valve	Sequence valve directs flow to more than one portion of a fluid circuit in sequence.
4.	Counterbalance valve (Back-pressure valve)	Counterbalance valve permits free flow in one direction and restricted flow in the opposite direction.
5.	Unloading valve	Unloading valve allows pressure to build up to an adjustable setting, then bypasses the flow as long as a remote source maintains the preset pressure on the pilot port.
6.	Pressure switch	Pressure switch is used when a pressure-actuated electric signal is required for system control.
7.	Hydraulic fuse	✓ Hydraulic fuse employs a frangible diaphragm, which establishes the maximum pressure in a hydraulic circuit by rupturing at a preset pressure valve. ✓ Hydraulic fuse, analogous to an electric fuse, is used to prevent the system pressure from exceeding beyond the allowable limit in order to protect the system components from damage.

However, we shall discuss the construction and operation of the pressure-limiting, pressure-reducing, and sequence valves, in details, in the following sections.

Note It may be noted that relief, sequence, counterbalance, and unloading valves are normally closed valves whereas the pressure-reducing valves are open valves.

7.13. PRESSURE-LIMITING VALVES (OR RELIEF VALVES)

7.13.1. What is a Pressure-Limiting Valve ?

- ✓ The pressure-limiting valve, also known as the ***relief valve***, is the protector of the hydraulic circuit.
- ✓ A relief valve limits the maximum pressure that can be applied to the part of the system to which it is connected.
- ✓ In other words, *a relief valve protects a system from excessive fluid pressure over and above the design pressure limit.*
- ✓ Normally the pressure relief valve is located in between the pump and the actuator. Thus the relief valve protects the pump, the electric motor, and also other components of the circuit.

7.13.1.1. Types of Relief Valves

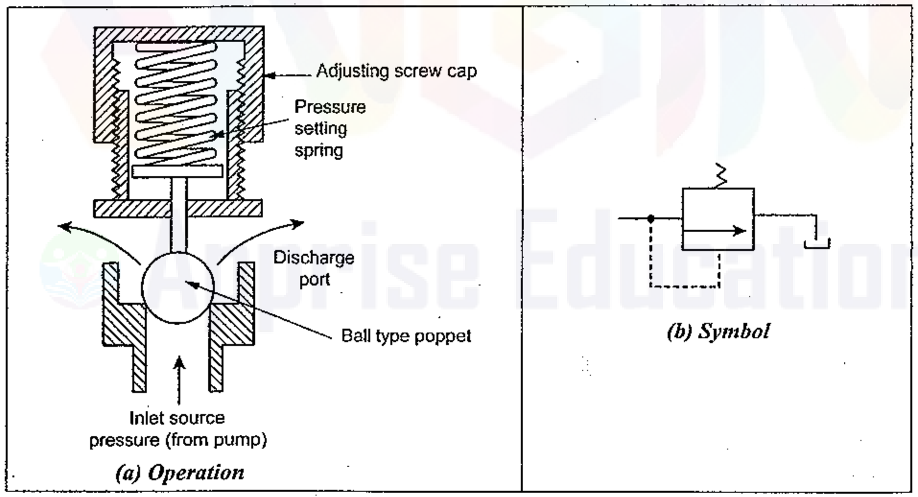
The two important types of pressure relief valves are :

1. Direct-acting or simple pressure relief valve, and
2. Pilot-operated or compound pressure relief valve.

7.14. SIMPLE (OR DIRECT ACTING) PRESSURE RELIEF VALVE

7.14.1. Construction and Operation

The construction and operation of a simple poppet (ball)-type direct-acting pressure valve is illustrated in Fig.7.16(*a*). It has one inlet port which is normally closed under the influence of spring force. An adjustable spring load provides the pressure setting of the relief valve.



(a) Operation

(b) Symbol

Fig. 7.16. Simple pressure relief valve

When the inlet pressure overcomes the force exerted by the spring, the valve opens and vents to the atmosphere or back to the sump. Thus the relief valve protects the other elements in the system from excessive pressure by diverting the excess fluid to the sump or atmosphere when the system pressure tends to exceed the preset level.

The direct-acting type of relief valves have a ball, poppet or a sliding spool working against a spring. As the inlet pressure decreases, the valve closes again. The adjusting screw cap is used to adjust the pressure limit and to vary the spring force.

7.14.2. Graphic Symbol

Fig.7.16(*b*) represents the graphic symbol of simple relief valve.

7.14.3. Application of Simple Relief Valves

The direct-acting pressure relief valves are used where the flow rate and the system pressure are low.

7.14.4. Limitation of Simple Relief Valves

When the required system pressure is high, a heavier spring is required. Because of the use of heavier spring, the problem of valve chatter or pressure fluctuations are very common.

7.15. COMPOUND (OR PILOT-OPERATED) PRESSURE RELIEF VALVE

7.15.1. Introduction

The compound pressure relief valve overcomes the problem of direct-acting pressure relief valve. Thus these relief valves can be employed for a larger flow rate and higher system pressure. These valves are built in two stages.

7.15.2. Construction and Operation

The construction of a typical sliding-spool type pilot-operated pressure relief valve is illustrated in Fig.7.17.

This compound relief valve operates in two stages :

Stage 1 : The first stage is the same as direct-acting type. As in the direct-acting type, the movable main poppet allows fluid to escape to the reservoir when the system pressure exceeds the setting of the valve. This first stage is shown on the right side of the valve. The main poppet is retained to its seal by a light spring.

Stage 2 : The second stage, also known as ***pilot stage***, is located on the left side of the valve. It contains a pilot valve poppet (also known as control poppet) which is held against a seat by an adjustable strong spring. The pressure limit can be adjusted by using an adjustment screw.

The inlet system pressure acts on both sides of the main poppet because of the small orifice shown in Fig.7.17. The fluid passes from the inlet port through the orifice to a control chamber where it acts on the main poppet to add to the spring force. The system pressure also acts on the pilot poppet as shown in Fig.7.17.

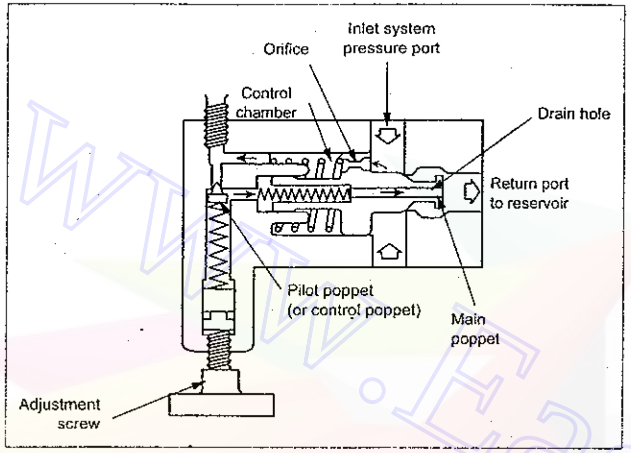


Fig. 7.17. Pilot-operated pressure-relief valve

When the system pressure exceeds the setting pressure of the main poppet, the poppet is pushed from its seat towards left. This forces the pressurised fluid on the left side to escape through the centrally drilled drain hole of the main poppet. This limits the pressure on the control chamber side. Due to the restricted flow through the orifice, the fluid cannot enter into the control chamber as quickly as the fluid leaves through the drain hole. Because of this, the pressure on the right side exceeds that on the left and the main poppet moves to the left. Thus it permits the fluid flow directly to the reservoir tank from the inlet port. When the pressure falls below the setting pressure, the main poppet retracts back to its original position again.

7.16. PRESSURE REDUCING/REGULATING VALVE

7.16.1. What is a Pressure Reducing Valve ?

- ✓ As the name suggests, *a pressure reducing valve is used to supply a prescribed reduced outlet pressure in a circuit and to maintain it at a constant value.*
- ✓ Generally this type of valves are used in multi-pressure systems where some part of the circuit is required to operate at a reduced pressure.

7.16.1.1. Types of Pressure Reducing Valves

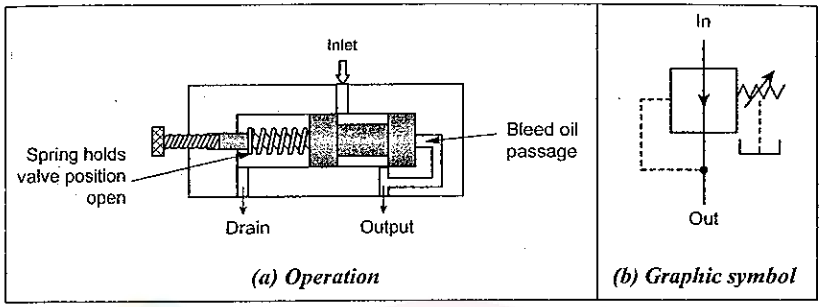
Like in pressure relief valves, the two important types of pressure reducing valves are :

1. Direct-acting pressure reducing valve, and
2. Pilot-operated pressure reducing valve.

7.17. DIRECT-ACTING PRESSURE REDUCING VALVE

7.17.1. Construction and Operation

The construction and operation of a direct-acting pressure reducing valve is illustrated in Fig.7.18(*a*). It has a spring loaded spool to control the downstream (outlet) pressure.



(a) Operation *(b) Graphic symbol*

Fig. 7.18. Pressure reducing valve

When the main supply pressure is below the valve setting pressure, fluid will flow freely from the inlet to the outlet. It can be noted from Fig.7.18 that an internal connection from the outlet passage transmits the outlet pressure to the spool end opposite the spring.

When the downstream (outlet) pressure increases to the valve setting pressure, the spool moves to the left to partly block the outlet port. During this period, only enough flow is passed to the outlet to maintain the preset pressure.

If the valve closes completely, leakage could cause the spool pressure to build up. In order to avoid this, a continuous bleed to the tank is permitted to keep the valve slightly open. A separate drain passage is provided to drain this fluid to the tank.

7.17.2. Graphic Symbol

Fig.7.18(*b*) shows a symbolic representation of a pressure reducing valve.

7.18. PILOT-OPERATED PRESSURE REDUCING VALVE

The pilot operated pressure reducing valves are built and operate on principles similar to the compound relief valves, described earlier in Section 7.15.

7.18.1. Analysis of kW Power Loss Across the Pressure Relief Valve

The kW power loss across the pressure relief valve (also for the unloading valve) can be determined by using the relation :

$$\boxed{\text{kW power loss} = P \times Q} \quad \ldots (7.1)$$

where P = Valve pressure setting in kPa, and

Q = Outlet flow rate in m³/s.

Note It should be noted that there are no valves available for increasing the system pressure. As discussed above, it is possible only to have a valve which will reduce the system pressure.

7.19. SEQUENCE VAVLES

7.19.1. What are Sequence Valves

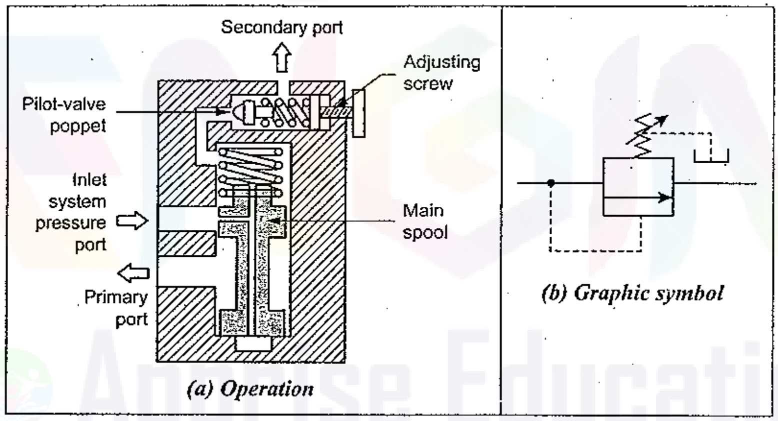
- ✓ *The sequence valves are used to control the fluid flow to ensure several operations in a particular order of priority in the system.*
- ✓ The sequence valves are another type of pressure control valves, which are also extensively used in hydraulic systems.
- ✓ These valves permit several operations to be completed in a sequential order, *i.e.*, one after another. For example, a pressure sequence valve used in a clamping and drilling circuit will permit the clamping operation to take place first and then the drilling operation is accomplished.
- ✓ The sequence valves are set to specific pressure levels so as to ensure the priorities of function.

7.19.1.1. Types of Sequence Valves

Sequence valves are basically relief valves with minor modifications and may be either of the direct-acting or compound type.

7.19.2. Pilot-Operated (or Compound) Sequence Valve

The construction and operation of a typical pilot-operated sequence valve is illustrated in Fig.7.19(*a*).



(a) Operation

(b) Graphic symbol

Fig. 7.19. Pilot operated sequence valve

When the system inlet pressure is within the preset valve pressure, the valve allows the fluid freely through the primary port to operate the first phase. When the system inlet pressure exceeds the preset valve pressure, the valve spool moves up. As the spool lifts, flow is diverted to the secondary port to operate the second phase.

The required sequential pressure can be adjusted with the help of the adjusting screw.

7.19.3. Graphic Symbol

Fig.7.19(*b*) represents the symbolic representation of a sequence valve.

7.20. FLOW CONTROL VALVES

7.20.1. What are Flow Control Valves ?

- ✓ *Flow control valves, also known as* ***volume-control valves,*** *are used to regulate the rate of fluid flow to different parts of a hydraulic system.*
- ✓ Since control of flow rate is a means by which the speed of hydraulic machine elements is governed, therefore flow control valves are also known as ***speed-control valves.***
- ✓ The flow rate to a particular system component is varied by throttling or by diverting the flow.

7.20.2. Types of Flow Control Valves

The two basic types of flow control valves are :

1. Non-pressure compensated flow control valves, and
   (*i*) Globe valve, and (*ii*) Needle valve.
2. Pressure compensated flow control valves.

7.21. NON-PRESSURE COMPENSATED FLOW CONTROL VALVES

7.21.1. What are Non-Pressure Compensated Flow Control Valves ?

- ✓ The non-pressure compensated type flow control valves are used where system pressures vary considerably and precise flow-rate controls are not required.
- ✓ These valves operate based on the principle that the flow through an orifice will be constant, if the pressure drop remains constant.
- ✓ All the simple valves such as globe, needle, butterfly, gate, and ball valves are non-pressure compensated valves.

7.21.2. Globe Valve

In a globe valve, flow rate can be changed by means of a disk, plug, or ball which nests against a seat, as shown in Fig.7.20, 7.21, and 7.22 respectively.

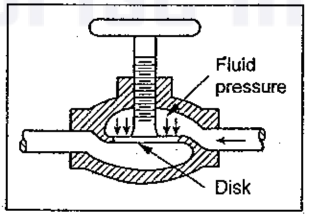


Fig. 7.20. Disk-type globe valve

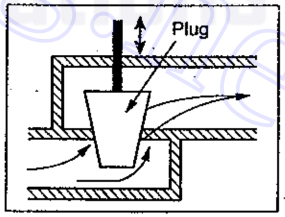


Fig. 7.21. Plug-type globe valve

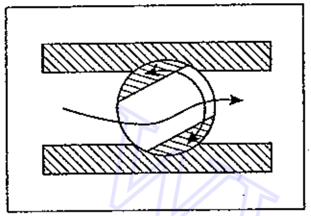


Fig. 7.22. Ball-type globe valve

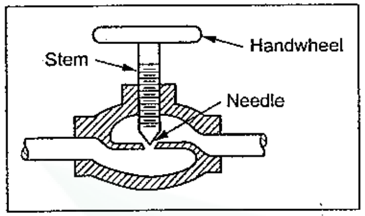


Fig. 7.23. Needle valve

1. Disk-type globe valve : Disk-type globe valve, also known as a ***butterfly valve,*** consists of a large disc which is rotated inside the pipe, the angle determining the flow rate, as shown in Fig.7.20.

2. Plug-type globe valve : Plug-type globe valve has a tapered plug that can control the flow rate by varying the vertical plug position, as shown in Fig.7.21.

3. Ball-type globe valve : Ball-type globe valve has a ball with a through-hole which is rotated inside a machined seat, as shown in Fig.7.22.

7.21.3. Needle Valve

- ✓ The needle valve has a pointed stem that can be adjusted manually to control the flow rate of fluid through the valve, as shown in Fig.7.23.
- ✓ Needle valves have a smaller flow area and higher pressure drop than the globe valve.

7.21.4. Applications of Non-Pressure Compensated Flow Control Valves

1. The globe valves are used to throttle only in lines where the liquid velocity is relatively low.
2. In comparison to globe valves, needle valves are more suitable in throttling the flow for any velocity.

7.21.5. Limitations of Non-Pressure Compensated Flow Control Valves

In both globe and needle valves, changes in the pressure drop produce variations in the flow rate. Therefore precise accuracy in flow-rate control and hence the speed control cannot be achieved by using non-pressure compensated flow control valves.

7.22. PRESSURE-COMPENSATED FLOW CONTROL VALVES

7.22.1. What are Pressure-Compensated Flow Control Valves ?

As we know the flow rate through any orifice depends upon the pressure difference between its inlet and outlet. Therefore a constant pressure drop across the valve orifice is required to assure accurate flow control. This is accomplished with the pressure-compensated flow control valve.

7.22.2. Construction and Operation

The construction and operation of a typical pressure-compensated flow control valve is illustrated in Fig.7.24.

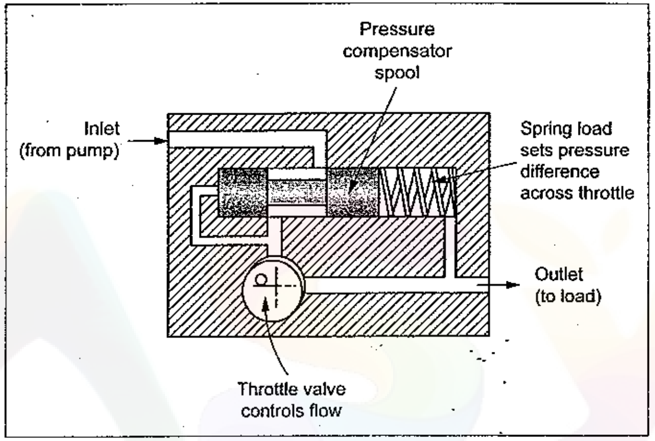


Fig. 7.24. Pressure-compensated flow control valve

The valve actually has two main parts arranged in series. They are :

1. Throttle valves : Similar to a needle valve, the throttle valve has an orifice whose area can be adjusted by an external knob setting. This throttle valve setting determines the flow rate is to be controlled.

2. Pressure compensator : The pressure compensator spool controls the size of the inlet orifice and maintains a constant pressure drop across the throttle valve.

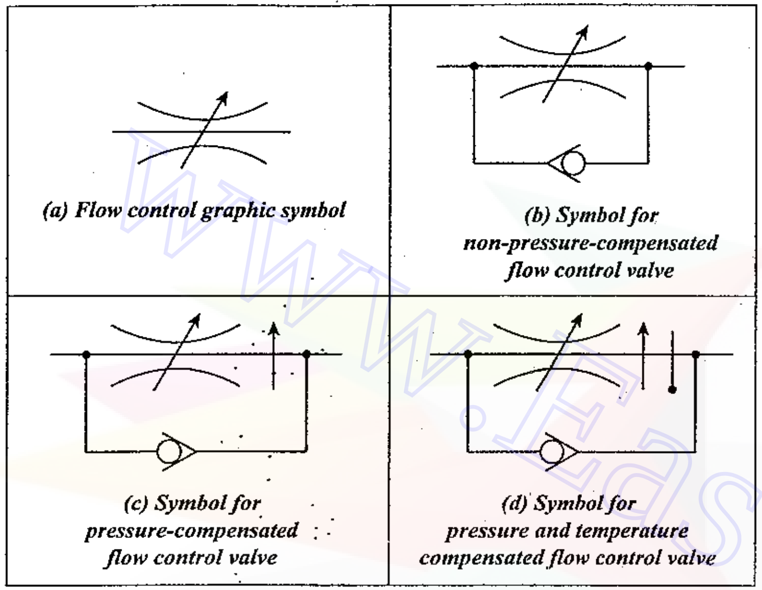
As inlet pressure increases and overcomes the spring force, the pressure compensator spool closes the inlet passage. It blocks off all flow in excess of the throttle setting. As a result, the valve permits the fluid flow only to the amount for which the throttle is already set.

When the fluid passes through the throttle valve, the pressure builds up in the spring side of the compensator. This pressure drop produces a rapid compensation in the form of spool motion. This spool adjustment causes the pressure drop to return quickly to its original valve, thus maintaining constant flow.

Note Flow control valves can also be affected badly by temperature changes which change the viscosity of the fluid. Therefore often flow control valves have temperature compensation.

7.22.3. Flow Control Valve Symbols

Fig.7.25 depicts graphic symbols for various types of flow control valves.



(a) Flow control graphic symbol

(b) Symbol for non-pressure-compensated flow control valve

(c) Symbol for pressure-compensated flow control valve

(d) Symbol for pressure and temperature compensated flow control valve

Fig. 7.25. Graphic symbols for various types of flow control valves

From Fig.7.25, one can interrupt the following points :

- ✓ The slash arrow (↗) across the orifice symbol represents that the orifice can be adjusted.
- ✓ The vertical arrow (↑) represents the pressure compensation.
- ✓ The vertical line with dot at the base (↓) represents temperature compensation.
- ✓ The symbol →○ represents unidirectional flow.

7.22.4. Relationship Between Flow Rate and Pressure Drop For a Flow Control Valve

The following equation relates the flow rate versus the pressure drop relationship for a needle valve :

$$\boxed{Q = C_v\sqrt{\frac{\Delta P}{S_g}}} \quad \ldots (7.2)$$

where Q = Volume flow rate in Lpm,

C_v = Capacity coefficient† in Lpm/$\sqrt{\text{kPa}}$,

---

† The term ***capacity coefficient*** may be defined as the flow rate of water in Lpm that will flow through the valve at a pressure drop of 1 kPa.

ΔP = Pressure drop across the valve in kPa, and

S_g = Specific gravity of the liquid.

Note ✓ In addition to the various hydraulic valves discussed so far, there are other valves available for other specific applications such as servo valves and cartridge valves.

- ✓ ***Servo valves*** are DC valves that have infinitely variable positioning capability. Thus they can control not only the direction of fluid flow but also the quantity of fluid. Servo valves along with feedback-sensing devices provide the very accurate control of position, velocity, and acceleration of actuators.
- ✓ ***Cartridge insert valves*** are used extensively in mobile hydraulic systems such as earth-moving equipment and refuse collectors. These inserts are in the form of screwed barrels, each of which contains a complete control function such as pressure relief or shock valve.

SOME ILLUSTRATIVE NUMERICAL PROBLEMS

On Pressure Control Valve

Example 7.1 ***A pressure relief valve has a pressure setting of 100 bars. Calculate the kW power loss across this valve if it returns all the flow back to the tank from a 1.39 Lps pump.***

Given Data : $P = 100$ bar $= 100 \times 10^2$ kPa ; $Q = 1.39$ Lps $= 1.39 \times 10^{-3}$ m³/s.

☺ ***Solution :*** We know that the kW power loss across the pressure relief valve,

$$\text{kW power loss} = P \cdot Q$$
$$= (100 \times 10^2)(1.39 \times 10^{-3}) = \mathbf{13.9\ kW} \quad \textbf{Ans.}$$

On Flow Control Valve

Example 7.2 ***Determine the flow rate through a flow control valve that has a capacity coefficient 3 Lpm/$\sqrt{\text{kPa}}$ and a pressure drop of 720 kPa. The fluid is hydraulic oil with a specific gravity of 0.90.***

Given Data : $C_v = 3$ Lpm/$\sqrt{\text{kPa}}$; $\Delta P = 720$ kPa ; $S_g = 0.90$.

☺ ***Solution :*** We know that the flow rate through a flow control valve,

$$Q = C_v\sqrt{\frac{\Delta P}{S_g}} = 3\sqrt{\frac{729}{0.9}} = 84.85 \text{ Lpm}$$

$$= \frac{84.85 \times 10^{-3}}{60} = \mathbf{0.0014\ m^3/s} \quad \textbf{Ans.}$$

REVIEW AND SUMMARY

- ✓ *In this chapter, the purpose, construction, operation, and graphic symbols of various control valves required for proper functioning of the hydraulic systems have been discussed.*
- ✓ ***Hydraulic valves*** *are devices used to control pressure, flow direction, or flow rate in hydraulic circuits.*

✓ ***Types of control valves :*** *Three basic types of control valves, based on their function in the hydraulic system, are :*

1. *Directional control valves,*
2. *Pressure control valves, and*
3. *Flow control valves.*

✓ ***Valves configuration :*** *Three essential types of valve configurations are :*

1. *Poppet (or seat) valves,*
2. *Sliding spool valves, and*
3. *Rotary spool valves.*

✓ *The function of a* ***directional control valve (DCV)*** *is to control the direction of flow in a hydraulic circuit.*

✓ *The* ***check valves,*** *also known as* ***non-return valves,*** *are used to allow free flow in only one direction, and to prevent any flow in the other direction.*

✓ ***The function of the position valve*** *is to control the introduction of liquid to the lines of the system.*

✓ *The* ***position valves*** *are usually described by their number of ports and positions. For example, a 4/2 valve has 4 ports and 2 positions.*

✓ *The purpose, construction, and operation of various directional control valves—check valves, 2/2 valves, 3/2 valves, 4/2 valves, 4/3 valves, and shuttle valves—are discussed, in detail.*

✓ ***Shuttle valves,*** *also known as* ***double check valves,*** *are used when control is required from more than one power source.*

✓ *The* ***pressure control valves*** *are the devices used to control the fluid pressure in a system.*

✓ ***Types of pressure control valves :*** *The three important types are :*

1. *Pressure limiting (or relief) valves,*
   (a) Simple pressure relief valves, and (b) Compound pressure relief valves.
2. *Pressure reducing (or regulating) valves, and*
3. *Sequence valves.*

✓ *The* ***pressure limiting valve,*** *also known as the* ***relief valve,*** *protects a system from excessive fluid pressure over and above the design pressure limit.*

✓ *The* ***pressure regulating valve*** *is used to supply a prescribed reduced outlet pressure in a circuit and to maintain it at a constant value.*

✓ *The* ***sequence valve*** *is used to control the fluid flow to ensure several operations in a particular order of priority in the system.*

✓ ***Flow control valves,*** *also known as* ***volume-control valves,*** *are used to regulate the rate of fluid flow to different parts of a hydraulic system.*

✓ ***Types of flow control valves :*** *The two basic types of flow control valves are :*

1. *Non-pressure compensated flow control valves, and*
   (i) Globe valves, and (ii) Needle valves.
2. *Pressure compensated flow control valves.*

✓ *This chapter also described the purpose, construction, operation, and graphic symbols of various pressure limiting valves and pressure sequence valves.*

✓ ***Formulae summary :***

For pressure relief valves :

$$\text{kW power loss} = P\,(\text{kPa}) \times Q\,(\text{m}^3/\text{s})$$

For flow control valves :

$$\text{Flow rate, } Q\,(\text{Lpm}) = C_v \left(\frac{\text{Lpm}}{\sqrt{\text{kPa}}}\right)\sqrt{\frac{\Delta P\,(\text{kPa})}{S_g}}$$

KEY TERMS ONE SHOULD REMEMBER

Hydraulic valves
Control valves
Valves configuration
  Poppet valves
  Sliding spool valves
  Rotary spool valves
Directional control valves
  Check valves
  Non-return valves
  Position valves
  Shuttle valves
2/2 DC valves
3/2 DC valves
4/2 DC valves
4/3 DC valves

Pressure control valves
  Pressure limiting valves
  Pressure reducing valves
  Sequence valves
  Counter balance valves
  Unloading valves
  Pressure switch
  Hydraulic fuse
Relief valves
  Simple pressure relief valves
  Compound pressure relief valves
Flow control valves
  Non-pressure compensated flow control valves
  Pressure compensated flow control valves

Volume control valves
Speed control valves
Globe valves
  Butterfly valves
  Plug-type valves
  Ball-type valves
Needle valves
Graphic symbols
Capacity coefficient

REVIEW QUESTIONS

Short Answer Type Questions

On Introduction to Hydraulic Valves

1. What are control valves ? What are the three important parameters that should be controlled in a hydraulic system ?

2. Name the three basic types of control valves based on their function ?
3. What are the three types of control valves based on their configuration ?
4. When do you prefer poppet type hydraulic valves ?
5. What are the advantages of sliding-spool type valves over the poppet type valves ?

On Directional Control Valves

6. What is the function of a directional control valve ?
7. What is a check valve ? What are its functions ?
8. What is the difference between a simple check valve and a pilot check valve ?
9. What do you mean by position valves ?
10. With reference to directional control valves, explain the terms way, part, and position.
11. What does a 4/3 control valve represent ?
12. List atleast four ways in which directional control valves can be actuated.
13. Draw the graphic symbol for the following DC valves :
    (*a*) Solenoid actuated, spring return 3/2 DC valve.
    (*b*) Push button operated, four way, two position, spring offset DC valve, and
    (*c*) Pilot actuated, four way, three position, spring centred DC valve.
14. What is a solenoid and how does it actuate the spool of a DC valve ?
15. How does an open-center type DC valve differ from a closed-center type DC valve ?
16. Mention the application of a (*i*) 3 way DC valve, and (*ii*) 4 way DC valve.
17. What is the purpose of a shuttle valve ?

On Pressure Control Valves

18. What are pressure control valves ? Mention their functions.
19. Name various types of pressure control valves.
20. Why is a pressure relief valve used in a hydraulic system ?
21. State the two basic types of pressure relief valves.
22. Distinguish between a pressure control valve and a pressure relief valve.
23. Why are compound pressure relief valves generally preferred over direct-acting pressure relief valves ?
24. What is the purpose of a pressure reducing valve ?
25. Draw the graphic symbols for the following pressure control valves :
    (*a*) Pressure relief valve,
    (*b*) Pressure reducing valve, and
    (*c*) Pressure sequence valve.
26. What is the purpose of a counter balance valve ?

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27. What is the function of a unloading valve ?
28. What is a pressure switch ?
29. What is the use of a hydraulic fuse ?
30. How does the function of a pressure relief valve differ from that of a hydraulic fuse ?
31. What are sequence valves ? When are they used ?

On Flow Control Valves

32. What are flow control valves ? Why they are referred as speed-control valves ?
33. Name few non-pressure compensated flow control valves.
34. What are the limitations of non-pressure compensated flow control valves ?
35. What do you mean by a pressure-compensated flow control valve ?
36. Why are flow control valves often temperature compensated ?
37. Draw the graphic symbol for a pressure compensated flow control valve.
38. With reference to a flow control valve, define the term capacity coefficient.

Essay Answer Type Questions

1. (*a*) Explain how poppet type DC valve and a sliding spool type DC valve differ in construction and operation.
   (*b*) Which of these two types are mostly used in a hydraulic system ? Why ?
2. (*a*) Where are check valves most commonly used ?
   (*b*) With a neat sketch, explain the construction and operation of a pilot check valve.
3. (*a*) Describe the construction and operation of a solenoid operated 3-way, 2-position directional control valve.
   (*b*) Explain the principle of a sliding-spool type 4/3 DC vale.
4. (*a*) Explain the different types of centres for a four-way three-position control valve and mention the applications.
   (*b*) How directional control valves are specified ?
5. Describe with the help of neat sketch the construction and operation of a shuttle valve.
6. Explain with a neat sketch, the construction, principle, and working of a compound relief valve. How the problems of simple relief valve are overcome using this valve. List the applications of the valve.
7. With a neat sketch, explain the principle and operation of a balanced piston relief valve.
8. (*a*) Explain the working of a direct-acting pressure reducing valve.
   (*b*) With a neat sketch, describe the construction and operation of a pilot-operated sequence valve.
9. (*a*) Write short notes on the globe and needle flow control valves.
   (*b*) What is meant by pressure compensated flow control valve ? With a neat sketch, explain how does pressure compensation take place.

PROBLEMS FOR PRACTICE

1. A pressure control valve has a pressure setting of 125 bars. Compute the kW power loss across this valve if it returns all the flow back to the tank from a 1.5 Lps pump.
[*Ans.* 18.75 kW]

2. A flow control valve experiences a pressure drop of 700 kPa for a flow rate of 1.6 Lps. The specific gravity of the fluid is 0.90. Determine the capacity coefficient.
[*Ans.* 3.44 $\text{Lpm}/\sqrt{\text{kPa}}$]

□□

Chapter 8

Accumulators and Intensifiers

"Think big thoughts but relish small pleasures."
– Jackson Brawn. Jr.

"However far modern science and techniques have fallen short of their inherent possibilities, they have taught mankind at least one lesson: Nothing is impossible."
– Lewis Mumford

"Men who accomplish great things in the industrial world are the ones who have faith in the money producing power of ideas."
– Charles Fillmore

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Understand and appreciate the functions and applications of accumulators.

☑ Discuss the purpose, construction, and operation of various types of accumulators.

☑ Calculate the capacity and sizing of the accumulators for an application.

☑ Describe the construction and operation of various accumulator circuits.

☑ Understand and appreciate the functions and applications of pressure intensifier.

☑ Explain the construction and operation of a pressure booster.

☑ Describe the construction and operation of various intensifier circuits.

Apprise Education, Reprise Innovations

CHAPTER 8 ACCUMULATORS AND INTENSIFIERS

8.1. INTRODUCTION

In addition to pumps, actuators, and valves, there are other ancillary devices are required to complete a hydraulic system. The important ancillary equipment and their functions are presented in Table 8.1.

Table 8.1. Ancillary equipment used in the hydraulic system

1. ***Fluid Reservoir :*** ✓ Reservoirs basically are used to provide a storage facility for the hydraulic fluid used by the system.

   ✓ In addition, the reservoirs also serve to separate entrained air, remove contaminants, and dissipate heat from the hydraulic fluid.

2. ***Filters and Strainers :*** ✓ Filters and strainers are devices for trapping/removing contaminants.

   ✓ Since the long-term operation of a hydraulic system depends on the cleanness of the hydraulic fluid used, therefore filters are necessarily used to prevent any contaminants from entering the system.

   ✓ Strainers are nothing but coarse filters.

3. ***Heat Exchangers (or Hydraulic Coolers) :*** ✓ Heat exchangers, also known as hydraulic coolers, are devices used to dissipate the heat generated in a hydraulic system.

   ✓ We know that heat is generated in all hydraulic systems. The main sources of heat include, the pump, motor, pressure relief valves, and flow control valves. Much of this heat is transferred to the hydraulic fluid, causing a rise in fluid temperature. Since all hydraulic fluids exhibit a limited temperature range over which the viscosity and lubricating characteristics are optimum, the heat must be dissipated to ensure satisfactory operation. This function is accomplished by the heat exchangers.

4. ***Accumulators :*** ✓ An accumulator, also known as ***pressure accumulator,*** is a device which can store hydraulic (pressure) energy.

   ✓ Accumulators can be used for pressure compensation, pulse damping, leakage compensation, emergency power, auxiliary pressure, and several other applications.

5.	***Intensifiers :*** ✓ An intensifier, also known as *pressure booster,* is a device used to compress the hydraulic fluid by a pressure greater than the system pressure generated by the primary pump. ✓ The intensifier convert a large-volume, low-pressure hydraulic fluid supply to a proportionately small-volume, high-pressure output.
6.	***Pressure gauges :*** ✓ Pressure gauges are used to measure the fluid pressure at various points in the system. ✓ Pressure measurement is considered as an important means of troubleshooting faulting operating hydraulic circuits. Pressure measurement can provide a good indication of leakage problems and faulty components such as pumps, motor, valves, and actuators. So pressure gauges are essential in any hydraulic system.
7.	***Pressure and Temperature Switches :*** ✓ ***A pressure switch*** is an instrument that automatically senses a change in pressure and opens or closes an electrical switching element when a predetermined pressure point is reached. ✓ ***A temperature switch*** is an instrument that automatically senses a change in temperature and opens or closes an electrical switching element when a predetermined temperature point is reached.
8.	***Shock Absorbers :*** ✓ A shock absorber is a device that brings a moving load to a gentle rest through the use of metred hydraulic fluid. ✓ The shock absorber accomplishes the 'smooth' deceleration by metering hydraulic fluid through orifices, converting work and kinetic energy into heat which is dissipated.
9.	***Hydraulic Piping :*** ✓ The function of hydraulic piping is to contain and conduct the hydraulic fluid from one port of the system to another. ✓ The design of the fluid conductors is just as important as the design of other components of a hydraulic system.

Out of these ancillary equipment, accumulators and intensifiers deserve detailed description. In this chapter, we shall present the purpose, construction, and operation of various accumulators and intensifiers used in the hydraulic system.

ACCUMULATORS AND ACCUMULATOR CIRCUITS

8.2. ACCUMULATORS

8.2.1. What are Accumulators ?

✓ *An accumulator is basically a pressure storage reservoir in which a non-compressible hydraulic fluid is retained under pressure from an external source.*

✓ In other words, hydraulic accumulator is a device used to store the energy of liquid under pressure and make this energy available as a quick secondary source of power to hydraulic machines (such as presses, lifts, and cranes).

✓ ***Example :*** In case of hydraulic crane or lift, the liquid under pressure needs to be supplied only during the upward motion of the load. This energy is supplied from hydraulic accumulator. But when the lift is moving downward, no large external energy is required and during that period the energy from the pump is stored in the accumulator.

✓ *Thus the function of hydraulic accumulator is analogous to that of the flywheel of a reciprocating engine and a* ***capacitor*** *in an electronic circuit.*

✓ ***Definition :*** A hydraulic accumulator is a device that stores the potential energy of an incompressible fluid held under pressure by an external source (such as pump) against some dynamic force (such as weight or gravity, mechanical force by springs, or pressurised gas).

8.2.2. Suitability and Applications of Accumulators

Suitability : Accumulators are suitable for the following types of applications :

1. For hydraulic shock suppression.
2. For fluid make-up in a closed hydraulic system.
3. For leakage compensation.
4. For source of emergency power in case of power failure.
5. For holding high pressures for long periods of time without keeping the pump unit in operation.

Applications : Accumulators in conjunction with hydraulic systems are used on large hydraulic presses, hydraulic lifts, hydraulic cranes, farm machinery, power brakes and landing gear mechanisms on airplanes, diesel engine starters, and other devices and machinery.

8.2.3. Types of Accumulators

Accumulators are classified in terms of the manner in which the load is applied. The three basic types of accumulators used in hydraulic systems are :

1. Weight-loaded (or dead-weight) accumulators,
2. Spring-loaded accumulators, and
3. Gas-loaded accumulators.

8.3. WEIGHT-LOADED (OR DEAD-WEIGHT) ACCUMULATORS

8.3.1. Construction

The construction and operation of a dead-weight type accumulator is illustrated in Fig.8.1. It consists of a piston rod or plunger loaded with a dead weight and moving within a cylinder to exert pressure on the hydraulic oil. The dead-weight provides the potential energy to compress the fluid. The dead-weight may be concrete block, iron or steel block, or any other heavy material. The piston should have a precision fit with the accumulator tube so as to reduce the leakage past the piston. One side of the accumulator cylinder is connected to the fluid source (pump) and the other side to the work load (machine).

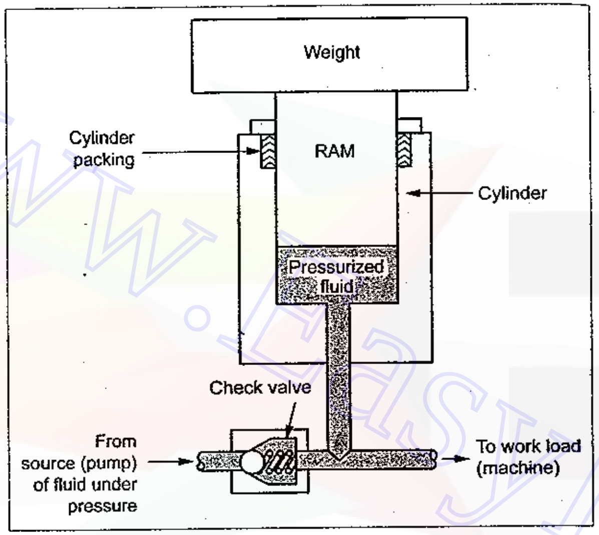


Fig. 8.1. Weight-loaded hydraulic accumulator

8.3.2. Operation

In the beginning, the ram is at the lower-most position. During idle periods of driven machine (say lift or crane) high pressure fluid (oil) supplied by the pump is admitted in the accumulator cylinder through the check valve. Fluid is allowed continuously till the ram reaches its uppermost position. At this position, the accumulator cylinder is full of fluid and the maximum amount of pressure energy is accumulated.

During the working stroke of the driven machine (*i.e.*, when it requires maximum amount of energy), the accumulated energy is discharged to the driven machine.

8.3.3. Advantages

The advantages of the weight-loaded type accumulators are :

1. The weight-loaded accumulators produce constant pressure for the full stroke *i.e.*, until all the fluid is sent out.
2. They can supply large volume of fluid under high pressure.
3. The large volume of fluid makes them possible to supply pressure to several hydraulic circuits.

8.3.4. Disadvantages

The weight-loaded type accumulators are not often used in modern hydraulic systems because of the following disadvantages :

1. They are very heavy and expensive.
2. They are not portable and hence cannot be used for mobile applications.
3. They also do not respond quickly to changes in the system demand.

8.4. SPRING-LOADED ACCUMULATORS

8.4.1. Construction

The spring-loaded accumulators are similar in construction to that of dead-weight type accumulators. In this type, instead of loading the ram with dead-weight, it is preloaded with compression spring, as shown in Fig.8.2. It consists of a cylinder body, a moveable piston, and a compression spring. The spring provides the compression energy required for this accumulator.

8.4.2. Operation

As the spring is compressed by the piston, the hydraulic fluid is forced into the accumulator cylinder. The pressure in the accumulator is dependent on the size and preloading of the spring. The accumulator pressure increases as the spring gets compressed, because incoming fluid flow increases the load required to compress the spring.

When the fluid is discharged out of the accumulator, it causes the spring to expand. As the spring approaches its free length, the accumulator pressure drops to a minimum. Thus the pressure exerted by the spring-loaded type accumulator on the fluid is not constant as in the dead-weight type.

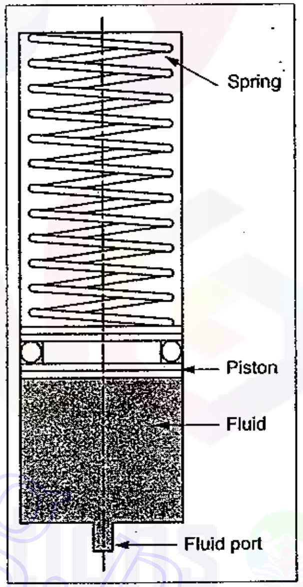


Fig. 8.2. Spring-loaded type accumulator

8.4.3. Advantages

1. The spring-loaded accumulators are usually smaller and less expensive than the dead-weight type accumulators.
2. They are easy to maintain.

8.4.4. Disadvantages

1. The pressure exerted of the fluid is not constant.

2. They are used mostly for low-volume, low-pressure systems.
3. For high-pressure and high-volume applications, they tend to be bulky and costly.

8.5. GAS-LOADED ACCUMULATORS

8.5.1. What are Gas-Loaded Accumulators ?

✓ Gas-loaded accumulators, also popularly known as ***hydro-pneumatic accumulators,*** are the most commonly used accumulators in almost all the industrial applications.

✓ They work on the basis of the Boyle's gas law. They Boyle's gas law states that for a constant temperature process, the pressure of the gas varies inversely with its volume. Mathematically,

$$P \propto \frac{1}{V} \quad \text{when T is constant,} \quad \text{or} \quad PV = \text{constant.}$$

✓ For example, when the gas is compressed more (say half the initial volume), then the pressure of the gas is increased (in this case, the pressure is doubled). This compressibility of gas accounts for the storage of potential energy. This potential energy forces the hydraulic fluid out of the accumulator when the gas expands due to reduction in system pressure.

8.5.2. Types of Gas-Loaded Accumulators

The two types of gas-loaded accumulators are :

1. Non-separator type, and
2. Separator type.
   (*a*) Piston type, (*b*) Diaphragm type, and (*c*) Bladder type.

In the non-separator type, the gas which provides the load is in direct contact with the hydraulic fluid, whereas in the separator type, they are separated by a piston, diaphragm, or bladder.

8.6. NON-SEPARATOR TYPE ACCUMULATORS

8.6.1. Construction

Fig.8.3 shows a diagram of a non-separated pneumatic-loaded actuator in a circuit. It consists of a fully enclosed shell containing a gas-charging valve on the top and an oil port on the bottom. The gas confines at the top and the oil remains at the bottom and there is no physical separator between them. Since the gas has direct contact with the oil, this type is termed as non-separator type accumulator.

8.6.2. Operation

In this accumulator type, pressurisation is achieved by introducing a pressurizing gas into a container above the oil level. When the system pressure increases, the oil enters through oil port and pushes the gas. The reduction of volume of gas increases its pressure. This gas pressure is used as the potential energy to force the oil out when it is required in the circuit. Limit switches, which are actuated by oil level, are usually used to limit pressure.

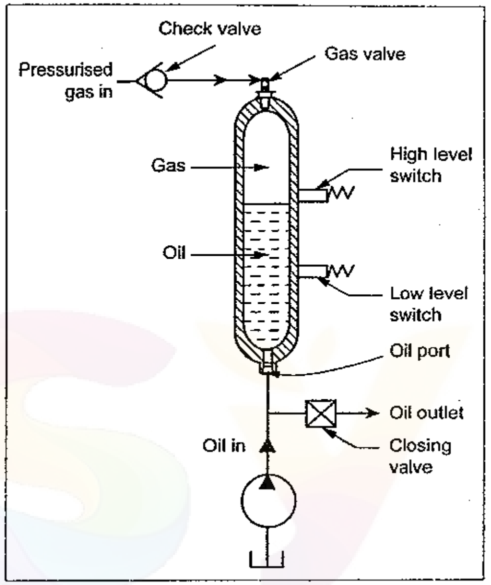


Fig. 8.3. Non-separator type accumulator

8.6.3. Advantages

The non-separator type accumulators can handle large volumes of oil.

8.6.4. Disadvantages

1. Due to the absence of separator, the gas is absorbed and also entrapped in the oil.
2. This accumulator type is not preferred for use with high speed pumps because the entrapped gas in the oil may cause cavitation and damage to the pump.
3. The absorption of gas in the oil makes the oil compressible, and thus results in spongy operation of hydraulic actuators.
4. Always this type of accumulator must be installed vertically so as to keep the gas confined at the top of the shell.
5. The problem of aeration of the oil often limits their use in hydraulic systems.

8.7. SEPARATOR TYPE ACCUMULATORS

✓ The above said drawbacks of the non-separator type accumulators can be eliminated in the separator type accumulators by providing a barrier between the pressurizing gas and the hydraulic fluid.

✓ The separator pneumatic-loaded accumulators are the most commonly used. Because they are small, light weight and can be mounted in any position.

✓ ***Types :*** Based on the barrier used, the separator type accumulators can be classified into three types, as :

1. Piston type accumulator,
2. Diaphragm type accumulator, and
3. Bladder type accumulator.

8.8. PISTON TYPE ACCUMULATOR

8.8.1. Construction

The construction and operation of a typical piston type accumulator is illustrated in Fig.8.4. It consists of a cylinder body and a moveable piston with proper seals.

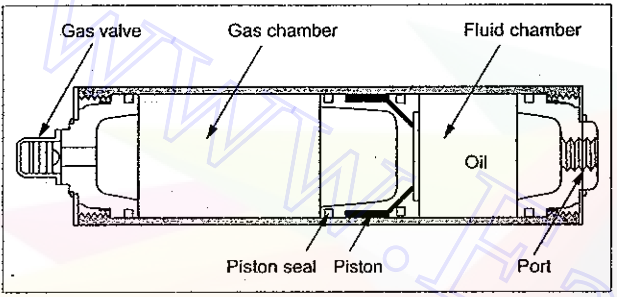


Fig. 8.4. Piston type accumulator

8.8.2. Operation

As shown in Fig.8.4, the piston serves as the barrier between the gas and oil. The gas is confined at the volume above the piston and the oil at the volume below the piston. The gas is compressed when the charged oil pushes the piston against it. This gas pressure is used as the potential energy to force the oil out when it is required in the circuit.

8.8.3. Advantage

The piston type accumulator has the ability to handle very high or low temperature system fluids.

8.8.4. Disadvantages

1. In piston type accumulators, the pressure does not remain constant when the complete oil is being displaced.
2. The piston type accumulators are expensive to manufacture.
3. In low-pressure applications, there may be a problem of piston and seal friction.
4. There is always appreciable leakage over a long period requiring frequency pre-charging.
5. Because of the inertia of the piston and friction of the seals, the piston type accumulators cannot be used as pressure pulsation dampeners or shock absorbers.

8.9. DIAPHRAGM TYPE ACCUMULATOR

8.9.1. Construction

The construction of a typical diaphragm-type accumulator is shown in Fig.8.5. The spherical vessel is separated into two compartments by a flexible diaphragm. One compartment is connected to the hydraulic system and the other to the high-pressure gas system. Thus the diaphragm serves as an elastic barrier between the oil and the gas.

8.9.2. Operation

In most designs, a spring-loaded, normally-open check valve or a screen is provided at the liquid connection to prevent extrusion of the diaphragm into the oil line when the fluid is discharged.

When the oil is delivered into the accumulator, it deforms the diaphragm. The gas is compressed when the charged oil pushes the diaphragm against it. This gas pressure is used as the potential energy to force the oil out when it is required in the circuit.

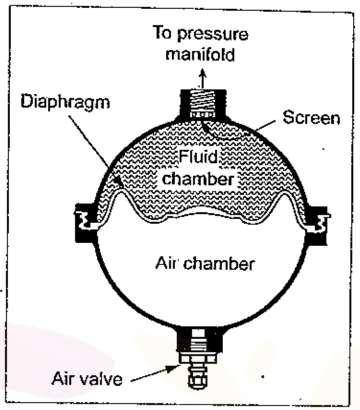


Fig. 8.5. Diaphragm-type gas-loaded accumulator

8.9.3. Advantages

The diaphragm type accumulator has small weight-to-volume ratio, which makes it most suitable for many air-borne applications.

8.9.4. Disadvantages

1. The diaphragm type accumulators do not provide constant fluid pressure outlet.
2. Sometimes the diaphragm material may become incompatible with certain fire resistant and synthetic fluids.

8.10. BLADDER TYPE ACCUMULATORS

8.10.1. Construction

The construction of a typical bladder type accumulator is depicted in Fig.8.6. It consists of a bag or bladder of synthetic material which is precharged with gas to a determined pressure. This bladder is placed within the accumulator shell and the balance of the space filled with oil. Thus the bladder serves as an elastic barrier between the gas and oil.

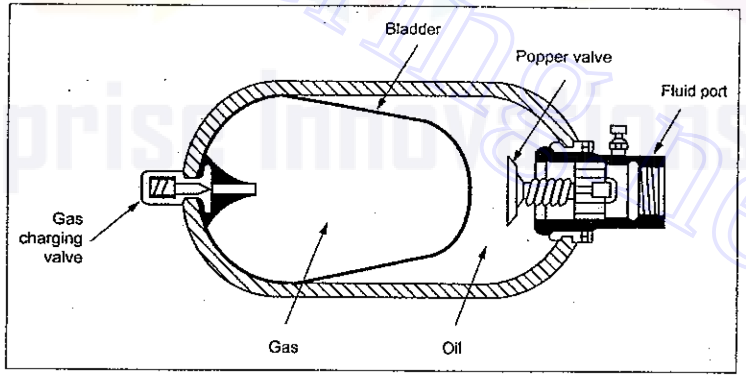


Fig. 8.6. Bladder-type gas-loaded hydraulic accumulator

8.10.2. Operation

When the fluid (oil) under pressure enters the accumulator, the gas in the bladder is compressive, thus forming a reservoir of pressure. When oil is called for from the accumulator, the bladder expands and forces the oil out into the circuit.

The large poppet valve, placed at the fluid entry port, closes when the accumulator is exhausted. This prevents the bladder from extruding out into the inlet pipe.

8.10.3. Advantages

1. The bladder type accumulators respond quickly to changes in the system demand.
2. They posses positive sealing between the gas and oil chambers.
3. Because of the low inertia of the bladder, they are especially suitable for damping pulsations.
4. This bladder type can be used for ratios of maximum to minimum pressure upto about 5 to 1.

8.10.4. Disadvantage

There is a possibility of bladder failure.

8.10.5. Other Important Concepts

1. Why is nitrogen gas preferred in a most of the gas-operated accumulators ?

The air or oxygen cannot be used in the system due to the danger of explosion. But the nitrogen gas is an inert and a non-poisonous gas. Since the nitrogen does not support combustion and does not combine easily with other elements, the nitrogen gas is preferred in most of the gas-operated accumulators.

2. Comparison of various gas-loaded type accumulators

Table 8.2 presents the comparison of important parameters of various gas-loaded type accumulators.

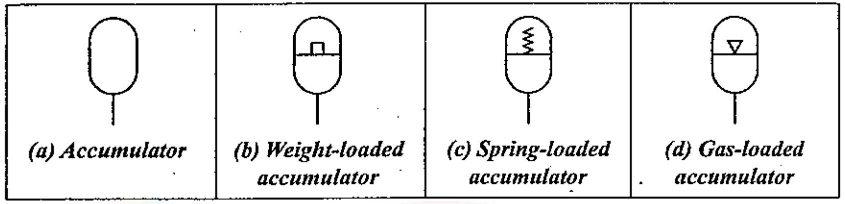
Table 8.2. Comparison of various gas-loaded type accumulators

Parameter / Type of accumulator	Maximum operating pressure, P_{max} (bar)	Safe pressure ratio = $\frac{P_a^{\dagger}}{P_{max}}$	Volumetric efficiency (%)
1. Piston type	200	Any	90 to 96
2. Diaphragm type	150	10	60
3. Bladder type	200	4	60

† P_a = Pre-charge pressure.

3. Accumulator Symbols

Fig.8.7 shows the various graphic symbols used to represent different types of accumulators.



(a) Accumulator

(b) Weight-loaded accumulator

(c) Spring-loaded accumulator

(d) Gas-loaded accumulator

Fig. 8.7. Various graphic symbols for accumulators

8.11. ACCUMULATOR CIRCUITS

As discussed in Section 8.2.2, accumulators are used as :

(i) Leakage compensator,
(ii) Auxiliary power source,
(iii) Emergency power source,
(iv) Hydraulic shock absorber,
(v) Fluid make-up device,
(vi) Holding device, and
(vii) Lubricant dispenser.

Now, we shall explain the operation of some accumulator circuits.

8.11.1. Accumulator as Leakage Compensator

✓ The stored energy of the accumulator can be used to compensate any possible loss of energy due to internal or external leakage in a system. (Usually, in situations when the system is pressurized but not in operation).

✓ This application is extremely helpful in circuits, such as are used for hydraulic presses, which require high pressure for long periods.

8.11.1.1. Circuit

Fig.8.8 illustrates a basic hydraulic circuit employing a bladder-type accumulator as a leakage compensator. This circuit consists of a power unit (pump), a check valve, 4/2 DC valve, pressure switch, power cylinder, and an accumulator.

8.11.1.2. Operation

First operator places workpiece on the press and shifts handle of the 4/2 DC valve. Now the oil flows to blind end of cylinder and piston extends contacting the work. The pressure builds up and oil fills the accumulator. When maximum pressure is reached, the pressure switch stops the pump motor.

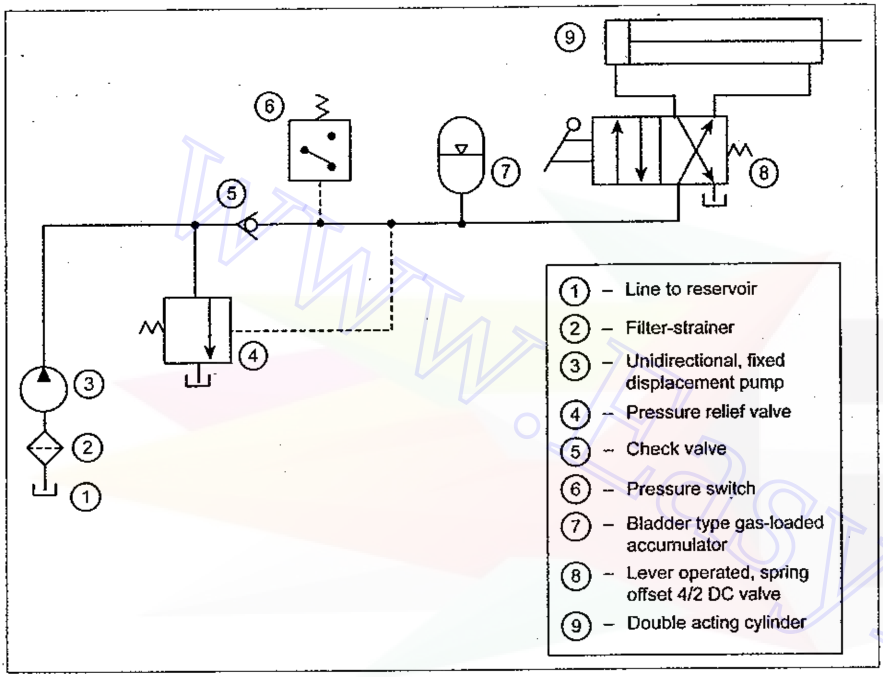

9
6
5
7
8
4
3
2
1
1 – Line to reservoir
2 – Filter-strainer
3 – Unidirectional, fixed displacement pump
4 – Pressure relief valve
5 – Check valve
6 – Pressure switch
7 – Bladder type gas-loaded accumulator
8 – Lever operated, spring offset 4/2 DC valve
9 – Double acting cylinder

Fig. 8.8. Accumulator as a leakage compensator

In these applications, the cylinder and piston arrangement is required to press the workpiece for a longer period of time. During this period, the internal and external leakage may reduce the cylinder pressure. The leakage oil is replaced with the oil from the accumulator. This leakage replacement of oil is carried for a longer period of time. The maximum length of time is determined by the volume of the accumulator and the rate of leakage in the cylinder.

Finally, when pressing cycle has been completed, the operator shifts the handle of the 4/2 DC valve to original position. Now the oil flows to the rod side of the piston and the piston is returned to starting position. Thus a cycle is completed.

The purpose of the check valve, in this circuit, is to prevent any reversal oil flow when the electric motor is stopped. The pressure relief valve is provided to protect against any overloads experienced by the actuators in the system.

8.11.1.3. Advantages

It may be noted that the power unit (the pump motor) operates only for a short period of time. That is, the power unit operates only when system pressure drops to the minimum pressure setting of the pressure switch. Thus, this arrangement saves electrical power and reduces heat in the system.

8.11.2. Accumulator as Auxiliary Power Source

- ✓ One of the most common uses of accumulators is to act as an auxiliary (or secondary) source of power. As we know, the electric motor or pump motor is the primary power source.
- ✓ In this application, the accumulator stores the oil during one portion of the work cycle and releases the oil during the remaining cycle. Thus the accumulator serves as a secondary power source.

8.11.2.1. Circuit

Fig.8.9 illustrates a basic hydraulic circuit employing a gas-loaded type accumulator for serving as a secondary power source.

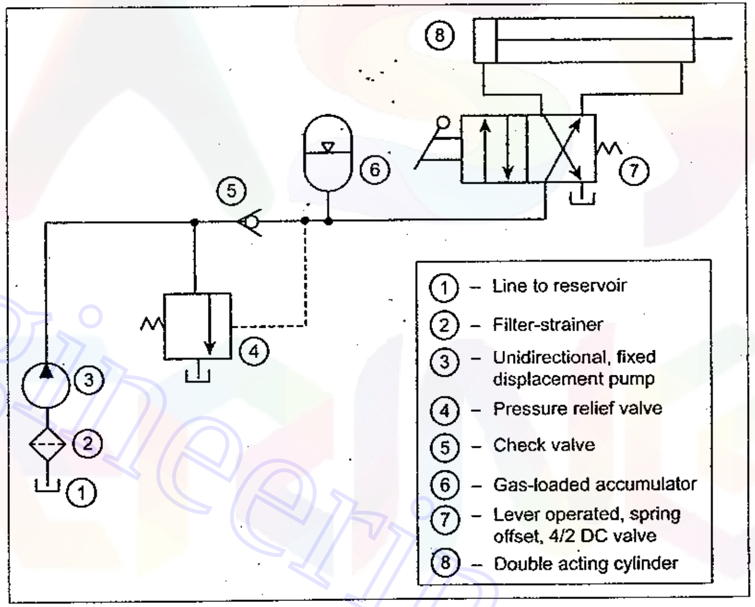

8
6
5
7
4
3
2
1
1 – Line to reservoir
2 – Filter-strainer
3 – Unidirectional, fixed displacement pump
4 – Pressure relief valve
5 – Check valve
6 – Gas-loaded accumulator
7 – Lever operated, spring offset, 4/2 DC valve
8 – Double acting cylinder

Fig. 8.9. Accumulator as an auxiliary power source

8.11.2.2. Operation

First operator places workpiece on slide-table and shifts handle of 4/2 DC valve. Now oil flows from the accumulator to blind end of slide cylinder. This extends the piston until slide table reaches end of stroke.

When the cylinder is in the fully extended position, the accumulator is charged with the oil by the pump. Then the operator shifts the handle of 4/2 DC valve for the retraction of the cylinder. Now the oil flows from the pump as well as from the accumulator to retract the cylinder quickly.

8.11.2.3. Advantage

The above application makes it possible to use a very small pump in conjunction with a large accumulator for producing the required performance.

8.11.3. Accumulator as Emergency Power Source

- ✓ In some hydraulic applications, it is necessary to retract the pistons of cylinders to their starting position (for safety reasons), even there may be an electrical power failure. In such applications, the accumulator can be used as an emergency power source to retract the piston of the cylinder.
- ✓ For example, consider a situation where a hydraulic system is operating a flood gate in a dam, and the electrical power fails. In such situation, the accumulator supplies the working fluid which operates the flood gate.

8.11.3.1. Circuit

Fig.8.10 illustrates how gas-loaded accumulator can be used as emergency source of power. This circuit essentially has a solenoid-operated 3/2 DC valve.

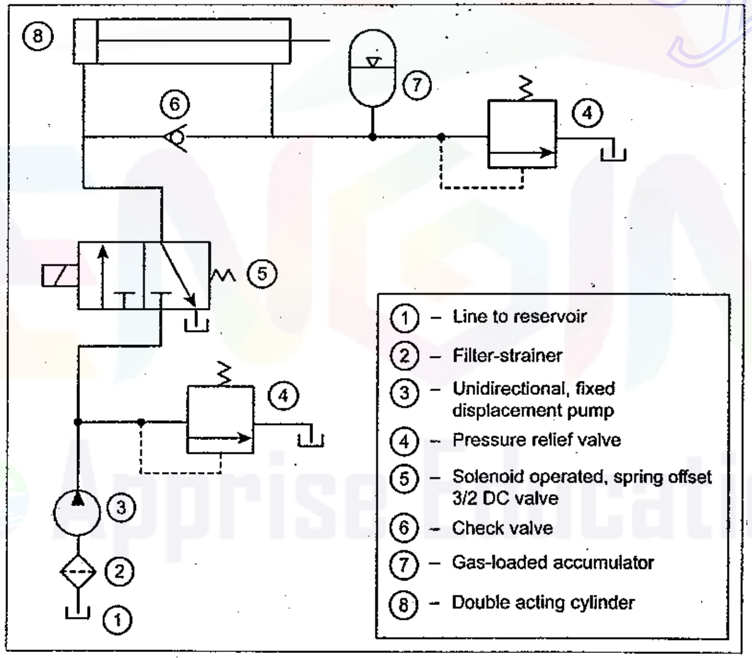

⑧
⑦
⑥
④
⑤
④
③
②
①
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Solenoid operated, spring offset 3/2 DC valve
⑥ – Check valve
⑦ – Gas-loaded accumulator
⑧ – Double acting cylinder

Fig. 8.10. Accumulator as an emergency power source

8.11.3.2. Operation

When operator depresses push button energizing solenoid of the 3/2 DC valve, oil flows to blind end of cylinder. At the same time, the oil also unseats check valve. So the oil under pressure flows to rod end of cylinder and into the accumulator. Now the accumulator charges the oil as the piston of cylinder extends.

When there is a power failure, the solenoid will deenergize. In the absence of solenoid-energy, the spring pressure forces the valve to shift to its spring-offset mode. Now the oil stored under pressure is forced from the bladder-type accumulator to the rod end of the cylinder. Thus the piston of the cylinder retracts to the starting position.

8.11.4. Accumulator as Hydraulic Shock Absorber

In many high-pressure hydraulic systems, the sudden stoppage or deceleration of a hydraulic fluid flowing at high velocity in pipelines can cause considerable damage to the piping. This hydraulic shock, also known as water hammer, may snap heavy pipes, loosen fittings and cause leaks. By installing an accumulator, this high-pressure pulsations or hydraulic shocks can be suppressed/absorbed.

8.11.4.1. Circuit

Fig.8.11 illustrates a basic hydraulic circuit employing a dead-weight type accumulator for serving as a hydraulic shock suppressor.

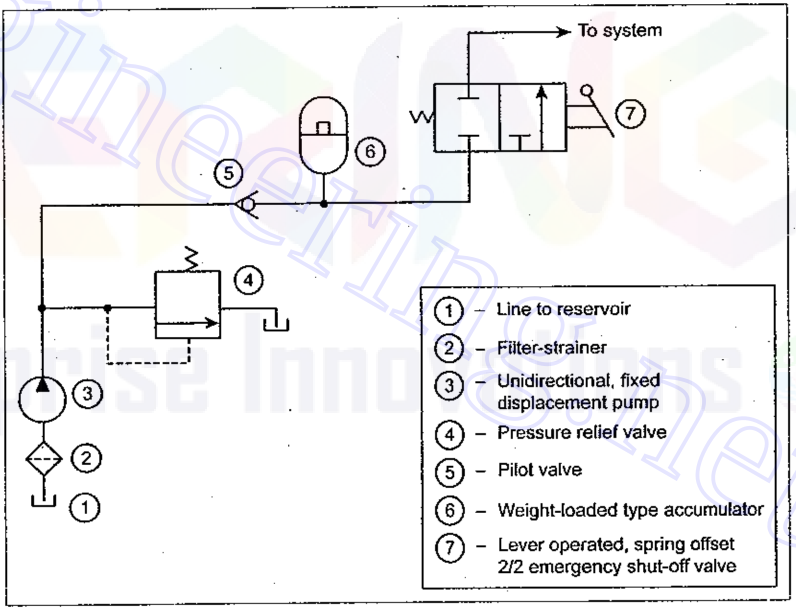

To system
⑦
⑥
⑤
④
③
②
①
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Pilot valve
⑥ – Weight-loaded type accumulator
⑦ – Lever operated, spring offset 2/2 emergency shut-off valve

Fig. 8.11. Accumulator as a hydraulic shock absorber

8.11.4.2. Operation

As shown in Fig.8.11, the accumulator is installed near the shut-off point in order to be more effective in quickly absorbing the shock wave. When the system demands to shut-off the supply suddenly, a 2/2 shut-off valve is used for the purpose.

When operator shifts handle of the 2/2 emergency shut-off valve, the fluid flow is stopped suddenly. This results in high-pressure pulsations or hydraulic shock. The pressure pulsation is blocked by check valve. The surges between the check valve and the shut-off valve is used to store the oil in accumulator and thus the pressure pulsations of the oil in the pipe line is absorbed.

8.12. SIZING OF ACCUMULATORS

8.12.1. Analysis of Weight-Loaded Type Accumulators

Fig.8.12 shows a simple weight-loaded type accumulator.

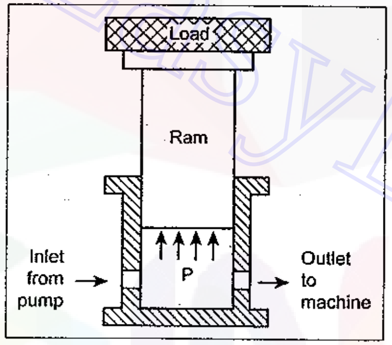


Fig. 8.12. Weight-loaded type accumulator

Capacity of accumulator : The maximum amount of energy that the accumulator can store is known as the capacity of the accumulator.

Derivation :

Let A = Area of the sliding ram $= \frac{\pi}{4} D^2$,

D = Diameter of the ram,

L = Stroke or lift of the ram,

P = Intensity of pressure of hydraulic fluid supplied by the pump, and

W = Total weight of the ram including the weight of the dead-load on the ram.

We know that, $W = P \times A$

Work done in lifting the ram $= W \times \text{Lift of ram}$

$= W \times L = P \times A \times L$ $\qquad [\because W = P \times A]$

But, $\left\{\begin{array}{c}\text{Work done in}\\ \text{lifting the ram}\end{array}\right\} = \left\{\begin{array}{c}\text{Energy stored in}\\ \text{the accumulator}\end{array}\right\} = \left\{\begin{array}{c}\text{Capacity of the}\\ \text{accumulator}\end{array}\right\}$

$\therefore$ $\boxed{\text{Capacity of the accumulator} = P \times A \times L}$ ... (8.1)

$= P \times \text{Volume of accumulator}$ ... (8.2)

Example 8.1 *An accumulator has a ram of 200 mm diameter and a lift of 6 m. If the hydraulic fluid is supplied at 60 bar, find : (i) the necessary load on the ram, and (ii) capacity of the accumulator.*

Given Data : $D = 200$ mm; $L = 6$ m; $P = 60$ bar.

☺ ***Solution :*** Area, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.2)^2 = 0.0314 \text{ m}^2$

(i) Load on the ram (W) :

$W = P \times A = (60 \times 10^3)(0.0314) = 1.884 \times 10^5$ N or **188.4 kN** **Ans.**

(ii) Capacity of the accumulator :

Capacity $= P \times A \times L = W \times L = (1.884 \times 10^5)(6)$

$= 11.304 \times 10^5$ N-m or **1130.4 kN-m** **Ans.**

Example 8.2 *An accumulator is loaded with 400 kN weight. The ram has a diameter of 300 mm and stroke of 6 m. Its friction may be taken as 5 percent. It takes two minutes to fall through its full stroke. Find the total work supplies and power delivered to the hydraulic appliance by the accumulator, when 0.0075 m³/s of liquid is being delivered by a pump, while the accumulator descends with the stated velocity. Take the density of oil as 1000 N/m³.*

Given Data : $W = 400$ kN ; $D = 300$ mm ; $L = 6$ m ; Friction = 5%.

☺ ***Solution :*** Area, $A = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.3)^2 = 0.07068 \text{ m}^2$

1. Total work supplied to the hydraulic machine :

Net load on accumulator when it descends = Actual load × (1 – % of friction)

$= 400 \times 0.95 = 380$ kN

Time taken by ram to fall through full stroke, t = 2 min or 120 s

$\therefore$ Distance moved by ram per sec $= \frac{1}{t} = \frac{6}{120} = 0.05$ m/s

Liquid supplied by pump $= 0.0075 \text{ m}^3/\text{s}$ ... (Given)

Work done by accumulator per second $= \left\{\begin{array}{c}\text{Net load}\\ \text{on ram}\end{array}\right\} \times \left\{\begin{array}{c}\text{Distance moved}\\ \text{by ram per sec}\end{array}\right\}$

$= 380 \times 0.05 = 19$ kNm/s

Intensity of pressure of liquid, $P = \frac{\text{Net load}}{\text{Area}}$

$= \frac{380 \times 10^3}{0.07068} = 5376.3 \times 10^3 \text{ N/m}^2$

We know that, $P = \rho g h$

or Pressure head, $H = \frac{P}{\rho g} = \frac{5376.3 \times 10^3}{1000 \times 9.81} = 548$ m

$$\text{Work supplied by pump per second} = \begin{Bmatrix}\text{Weight of}\\ \text{water supplied}\\ \text{per sec}\end{Bmatrix} \times \begin{Bmatrix}\text{Pressure}\\ \text{head}\end{Bmatrix}$$

$$= w\,Q\,H$$

$$= 9810 \times 0.0075 \times 548 = 40.319 \text{ kNm/s}$$

$$\therefore \quad \begin{Bmatrix}\text{Total work supplied to}\\ \text{hydraulic machine}\end{Bmatrix} = \begin{Bmatrix}\text{Work supplied}\\ \text{by accumulator}\end{Bmatrix} + \begin{Bmatrix}\text{Work supplied}\\ \text{by the pump}\end{Bmatrix}$$

$$= 19 + 40.319 = \mathbf{59.319\ kNm/s} \quad \textbf{Ans.}$$

2. Power delivered to the hydraulic machine :

$$\text{Power delivered} = \text{Work supplied per second}$$

$$= 50.319 \text{ kNm/s} = \mathbf{59.319\ kW} \quad \textbf{Ans.}$$

8.12.2. Analysis of Gas-Loaded Accumulators

- ✓ As we have discussed in Section 8.5, gas-loaded accumulators are governed by the Boyle's gas law. That means, the compression and expansion of the gas in gas-loaded accumulators are governed by the Boyle's law of gas.
- ✓ The rate of discharge determines whether the process is isothermal or adiabatic. If the rate of discharge is quick, the expansion process can be assumed to be adiabatic ($P_1V_1^{\gamma} = P_2V_2^{\gamma}$). Isothermal ($P_1V_1 = P_2V_2$) relations can be used for compression if the process is slow.
- ✓ The precharge pressure should be selected so that use is made of all liquid in the accumulator.
- ✓ $\begin{Bmatrix}\text{Size or total volume}\\ \text{of the accumulator}\end{Bmatrix} = \begin{Bmatrix}\text{Volume of the compressed}\\ \text{gas supplied}\end{Bmatrix} + \begin{Bmatrix}\text{Volume of the liquid}\\ \text{required by the system}\end{Bmatrix}$

The compressed gas volume is a function of the charge and discharge time. The required liquid volume can be determined from the performance of the accumulator.

The following solved numerical problems explain how the sizing of the gas-loaded accumulator can be determined in hydraulic circuits.

Example 8.3 *A gas-loaded accumulator has the following data :*

Precharge pressure = 125 bar

Charge accumulator (or maximum) pressure = 200 bar

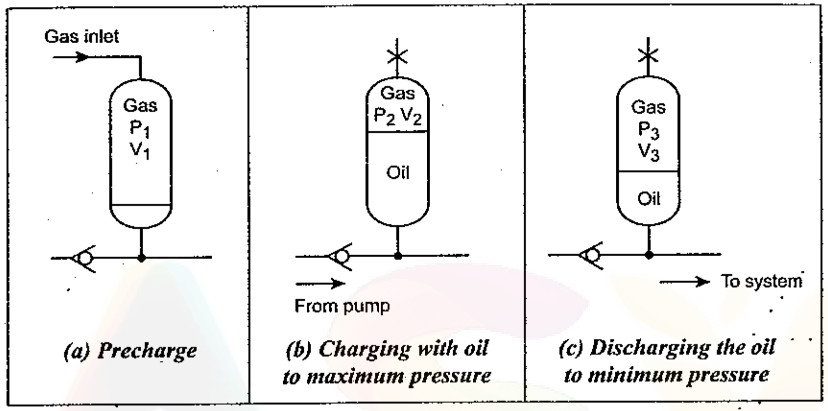
Pressure falls from 200 bar to 175 bar when 20 litres of oil is discharged.

What is the size (i.e., volume) of the accumulator used ? Take the charging and discharging processes as isothermal.

Given Data : $P_1 = 125$ bar ; $P_2 = 200$ bar ; $P_3 = 175$ bar ;

$$\text{Volume of oil discharged} = 20 \text{ litres} = 20 \times 10^{-3} \text{ m}^3.$$

☺ ***Solution :*** Fig.8.13 shows the three important states of the accumulator operation.



(a) Precharge

(b) Charging with oil to maximum pressure

(c) Discharging the oil to minimum pressure

Fig. 8.13. Three states of the accumulator operation

For isothermal process,

$$P_1V_1 = P_2V_2 = P_3V_3$$

From Figs.8.13(*b*) and (*c*), we can write

$$P_2V_2 = P_3V_3$$

or $\quad P_2(V_3 - 20 \times 10^{-3}) = P_3V_3 \qquad [\because \text{ 20 litres of oil is discharged}]$

or $\quad (200 \times 10^5)(V_3 - 20 \times 10^{-3}) = (175 \times 10^5)\,V_3$

or $\quad V_3 = 0.16 \text{ m}^3$

From Figs.8.13(*a*) and (*c*), we can write

$$P_1V_1 = P_3V_3$$

$$(125 \times 10^5)\,V_1 = (175 \times 10^5)(0.16)$$

or $\quad$ Accumulator volume, $V_1 = \mathbf{0.224\ m^3}$ or **224 litres** **Ans.**

Example 8.4 ***The accumulator of Fig.8.14 is to supply 8000 cm³ of oil with a maximum pressure of 225 bars and a minimum pressure of 140 bars. If the nitrogen precharge pressure is 95 bars, find the size of the accumulator. The hydraulic cylinder piston diameter is 200 mm.***

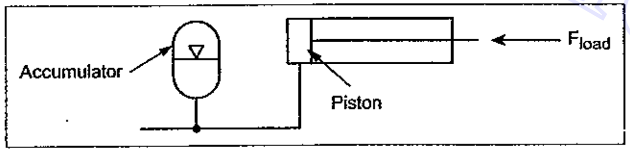


Fig. 8.14.

Given Data : Discharge of oil = 8000 cm^3 = 8000×10^{-6} m^3 ; $P_{max} = P_2 = 225$ bars;

$P_{min} = P_3 = 140$ bars ; $P_{precharge} = P_1 = 95$ bars ; D = 200 mm.[†]

☺ ***Solution :*** The solution to this problem is quiet similar to the previous solved problem. So proceeding in the same way, we get the solution as below :

Using Boyle's gas law, we write

$$P_1 V_1 = P_2 V_2 = P_3 V_3$$

First take,
$$P_2 V_2 = P_3 V_3$$

or
$$P_2 (V_3 - 8000 \times 10^{-6}) = P_3 V_3$$

or
$$(225 \times 10^5)(V_3 - 8000 \times 10^{-6}) = (140 \times 10^5) V_3$$

or
$$V_3 = 0.0212 \text{ m}^3$$

Now use,
$$P_1 V_1 = P_3 V_3$$

or
$$(95 \times 10^5) V_1 = (140 \times 10^5)(0.0212)$$

or
$$V_1 = \mathbf{0.0312 \text{ m}^3 \text{ or } 31.2 \text{ L}} \quad \textbf{Ans.}$$

Example 8.5 *For the accumulator of Example 8.4, find the load force F_{load} that the cylinder can carry over its entire stroke. What would be the total stroke of the cylinder if the entire output of the accumulator were used ?*

Given Data : Refer Example 8.4.

☺ ***Solution :*** Since the pressure of the oil supplied by the accumulator to the cylinder varies from maximum (225 bars) to minimum (140 bars), we can consider the average pressure $\left(\frac{225 + 140}{2} = 182.5 \text{ bars}\right)$ for our calculations.

1. Load force (F_{load}) :

We know that,
$$P_{oil} = F_{load} \times \text{Area of cylinder piston}$$

or
$$F_{load} = \frac{P}{A_p}$$

Here
$$A_p = \frac{\pi}{4} D^2 = \frac{\pi}{4} (0.2)^2 = 0.0314 \text{ m}^2$$

$$\therefore \quad F_{load} = \frac{182.5 \times 10^5}{0.0314} = \mathbf{580.9 \text{ MN}} \quad \textbf{Ans.}$$

2. Total stroke of the cylinder (L) :

Given that the entire output of the accumulator (*i.e.*, $V_1 = 0.0312$ m^3 of volume) were used.

[†] This data is a superfluous data. That means, this data may be an important data, but not required to solve this particular problem.

$$\therefore \text{ Total stroke of the cylinder} = \frac{\text{Volume of oil used}}{\text{Area of piston}}$$

$$= \frac{0.0312}{0.0314} = \mathbf{0.9936 \text{ m}} \quad \textbf{Ans.}$$

Example 8.6 ***A hydraulic circuit has been designed to crush a car body into bale size using a 175 mm diameter hydraulic cylinder. The hydraulic cylinder is to extend 2.4 m during a period of 10 s. The time between crushing strokes is 6 min. The accumulator has the following other details :***

Gas precharge pressure = 90 bars

Gas charge pressure when pump is turned on = 225 bars

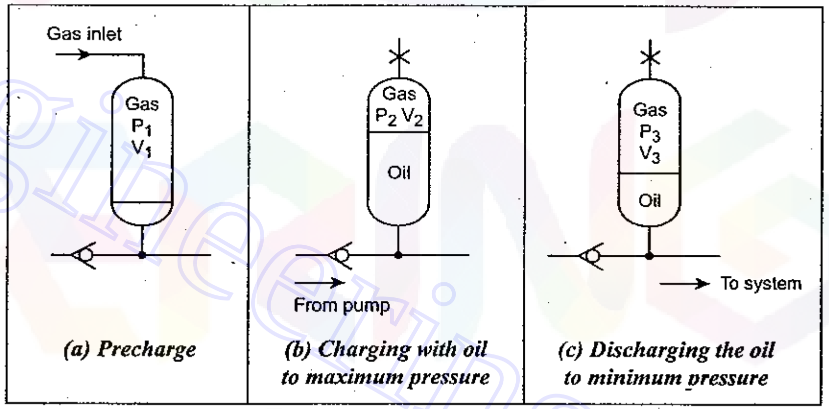
Minimum pressure required to actuate load = 125 bars

(i) Calculate the required size of the accumulator.

(ii) What are the pump flow requirements and the pump hydraulic kW power with and without an accumulator ?

Given Data : D = 175 mm ; Extension = 2.4 m ; $P_{precharge} = P_1 = 90$ bars ; $P_{charge} = P_{max} = P_2 = 225$ bars ; $P_{min} = P_3 = 125$ bars.

☺ ***Solution :*** Fig.8.15 shows the three important states of the accumulator operation.



(a) Precharge

(b) Charging with oil to maximum pressure

(c) Discharging the oil to minimum pressure

Fig. 8.15. Three states of the accumulator operation.

The hydraulic cylinder diameter and stroke (extension) are given. Therefore the volume of the hydraulic cylinder is calculated as

$$V_{hydraulic\ cylinder} = \left[\frac{\pi}{4} D^2\right] L = \left[\frac{\pi}{4} (0.175)^2\right] (2.4) = 0.0577 \text{ m}^3$$

Also, it should be noted from Figs.8.15(b) and (c) that the volume of oil displaced $(V_3 - V_2)$ from the accumulator is nothing but the volume of oil in the hydraulic cylinder.

$$\therefore \quad V_{hydraulic\ cylinder} = V_3 - V_2 = 0.0577 \text{ m}^3 \qquad \ldots (i)$$

(i) Size of the accumulator (V_1) :

We know that, $P_1 V_1 = P_2 V_2 = P_3 V_3$

For Figs.8.15(*b*) and (*c*), we can write

$$P_2 V_2 = P_3 V_3$$

or

$$V_3 = \frac{P_2 V_2}{P_3} = \frac{(225 \times 10^5)\, V_2}{(125 \times 10^5)} = 1.8\, V_2 \qquad \dots (ii)$$

On solving equations (*i*) and (*ii*), we get

$$V_2 = 0.072 \text{ m}^3 \text{ and } V_3 = 0.1298 \text{ m}^3$$

Now for Figs.8.15(*a*) and (*b*), we can write

$$P_1 V_1 = P_2 V_2$$

or Size of the accumulator,

$$V_1 = \frac{P_2 V_2}{P_1} = \frac{(225 \times 10^5)(0.072)}{(90 \times 10^5)} = \mathbf{0.18\ m^3} \text{ or } \mathbf{180\ L} \quad \textbf{Ans.}$$ ☜

(ii) Pump flow rate (Q_{pump}) and pump kW power (kW_{pump}) :

(a) With accumulator : It is given that the time between crushing strokes is 6 min (360 sec). It means that within 6 min time the pump must recharge the accumulator only and to the extent of the volume displaced in the cylinder during extension and retraction. This volume is equal to 2 ($V_3 - V_2$).

$$\left.\begin{array}{r}\text{Volume of oil pumped while}\\ \text{charging the accumulator}\end{array}\right\} = 2\,(V_3 - V_2)$$

$$= 2\,(0.1298 - 0.072) = 0.1156 \text{ m}^3$$

Then the pump flow rate,

$$Q_{pump} = \frac{\text{Volume of oil pumped}}{\text{Time taken}} = \frac{0.1156}{360}$$

$$= \mathbf{3.21 \times 10^{-4}\ m^3/s} \text{ or } \mathbf{0.321\ L/s} \quad \textbf{Ans.}$$ ☜

We know that the kW power,

$$kW_{pump} = \frac{P\ (\text{N/m}^2) \times Q\ (\text{m}^3/\text{s})}{1000}$$

$$= \frac{(225 \times 10^5)(3.21 \times 10^{-4})}{1000} = \mathbf{7.22\ kW} \quad \textbf{Ans.}$$ ☜

(b) Without accumulator : When there is no accumulator, then the pump flow rate is given by

$$Q_{pump} = \frac{\text{Volume of oil pumped to the hydraulic cylinder}}{\text{Time taken for the extension stroke}}$$

$$= \frac{V_{hydraulic\ cylinder}}{\text{Time taken}} = \frac{0.0577}{10}$$

$$= 0.00577 \text{ m}^3/\text{s} \text{ or } \mathbf{5.77\ L/s} \quad \textbf{Ans.}$$ ☜

Then

$$kW_{pump} = \frac{P \times Q}{1000} = \frac{(125 \times 10^5)(0.00577)}{1000} = \mathbf{72.125\ kW} \quad \textbf{Ans.}$$ ☜

Comment : From the above results, it may be noted that by employing the accumulator, the pump size and the pump kW power requirement can be drastically reduced.

INTENSIFIERS AND INTENSIFIER CIRCUITS

8.13. INTENSIFIER

8.13.1. What are Pressure Intensifiers ?

- ✓ Pressure intensifiers, also known as ***pressure boosters***, are used to compress the liquid in a hydraulic system to a value above the pump discharge pressure.
- ✓ In other words, *a hydraulic intensifier is a device which converts a large-volume, low-pressure fluid supply into a proportionately small-volume, high-pressure fluid outlet.*
- ✓ The intensifier is usually located in between the pump and the machine (*e.g.*, press, crane, lift) that needs high pressure liquid for its operation.
- ✓ The action of the intensifier is similar to that of a ***step-up electrical transformer.***
- ✓ It finds its application at places where a liquid of very high pressure is to be developed from available low pressure. Typical applications include hydraulic presses, riveting machines, and spot-welders.

8.13.2. Construction and Working

The construction and operation of a typical pressure intensifier is illustrated in Fig.8.16.

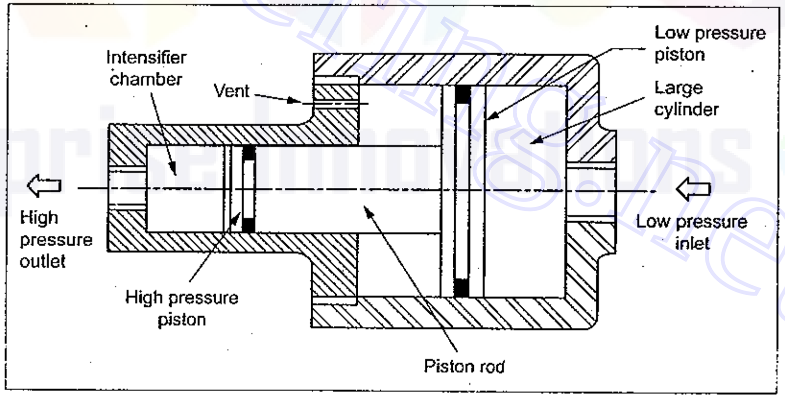


Fig. 8.16. Operation of a pressure intensifier

As shown in Fig.8.16, the unit consists of two pistons—low pressure and high pressure—having a common piston rod. The larger, piston is exposed to pressure from a low-pressure pump. The low-pressure fluid (oil) is introduced to the larger piston side and thus it forces the piston to move. Neglecting losses due to friction, the smaller end of the piston exerts the same force on the fluid in the intensifier chamber or smaller cylinder.

8.13.3. Intensifier Ratio

It may be noted that the increase in pressure is directly proportional to the difference in areas of the two sizes of pistons.

Let P_o = Pressure exerted on larger or 'operating' end of the piston,

P_i = Pressure exerted by smaller or 'intensifying' end of the piston,

A_o = Area of the larger or 'operating' end of the piston, and

A_i = Area of the smaller or 'intensifying' end of the piston.

Since force load acting on the two pistons is same, we get

$$P_o \times A_o = P_i \times A_i$$

or

$$\boxed{\text{Intensifier ratio, } \frac{P_i}{P_o} = \frac{A_o}{A_i}} \qquad \ldots (8.3)$$

The volume output is inversely proportional to the above ratio. Therefore we can write,

$$\frac{\text{High outlet pressure } (P_i)}{\text{Low inlet pressure } (P_o)} = \frac{\text{Area of large piston } (A_o)}{\text{Area of small piston (or piston rod) } (A_i)}$$

$$= \frac{\text{High inlet flow rate } (Q_{in})}{\text{Low outlet flow rate } (Q_{out})} \qquad \ldots (8.4)$$

8.13.4. Advantages

Some of the important advantages of employing the pressure booster are as follows :

1. In circuits which require low-volume high-pressure flow over short period, the pressure intensifier eliminates the need of expensive, high-pressure pumps.
2. This unit is more compact and simple than adding another power unit for high-pressure cycling.
3. A low power input can be used to maintain a high pressure for a period of time.
4. Because of the seal between the high- and low-pressure chambers, the intensifier can be operated with a liquid different from that used in the high-pressure part of the circuit.
5. Since the high-pressure is produced with small volume of oil, the heat generated is minimum.
6. It automatically connects with the circuit when high-pressure is required and disconnects when the demand is satisfied.
7. Its kW power requirements remain constant.

8.13.5. Ranges

The pressure intensifiers are available with pressure ratio ranging upto 50 to 1, developing pressures to 350 bar, and flow rate to 0.5 Lps.

8.13.6. Applications

Intensifiers find most useful applications where the output pressures requires are much higher than are obtainable from a pump. Typical applications include punching presses, riveting machines, spot-welders, and in many high-pressure testing machines such as tubing fixtures for testing bursting pressures and high pressure holding fixtures.

Example 8.7 ***A hydraulic fluid at 2 Lps and 75 bar enters the low-pressure inlet of a 5 : 1 pressure booster. Find the discharge pressure and flow rate.***

Given Data : $Q_{in} = 2 \text{ Lps} = 2 \times 10^{-3} \text{ m}^3/\text{s}$; $P_o = 75$ bar ; $\dfrac{P_i}{P_o} = \dfrac{5}{1} = 5.$

☺ ***Solution :*** Given that, $\dfrac{P_i}{P_o} = \dfrac{5}{1} = 5$

∴ Discharge pressure, $P_i = 5\,P_o = 5\,(75) = \mathbf{375\ bar}$ **Ans.** ☜

We know that, $\dfrac{P_i}{P_o} = \dfrac{Q_{in}}{Q_{out}}$

or $\dfrac{5}{1} = \dfrac{2 \times 10^{-3}}{Q_{out}}$

or Discharge flow rate, $Q_{out} = \mathbf{4 \times 10^{-4}\ m^3/s}$ or **0.4 Lps** **Ans.** ☜

Example 8.8 ***A hydraulic intensifier gets the low pressure liquid at a pressure of 50 bar and delivers it to a machine at a pressure of 150 bar. If the intensifier has a capacity of 0.025 m³ and stroke 1.25 m, calculate the diameters of the intensifier chamber and the larger cylinder to be used for this intensifier.***

Given Data : $P_o = 50$ bar ; $P_i = 150$ bar ; Capacity = 0.025 m^3 ; Stroke = 1.25 m.

☺ ***Solution : (i) Diameter of the intensifier chamber (D_i) :***

We know that,

Capacity of intensifier = Area of intensifier chamber (A_i) × Stroke length

or $0.025 = A_i \times 1.25$

or $A_i = 0.02 \text{ m}^2$

We know that, $A_i = \dfrac{\pi}{4} D_i^2 = 0.02 \text{ m}^2$

or $\left.\begin{matrix}\text{Diameter of}\\ \text{intensified cylinder}\end{matrix}\right\}$, $D_i = \mathbf{0.1596\ m}$ or **159.6 mm** **Ans.** ☜

(ii) Diameter of the larger cylinder (D_o) :

For the pressure intensifier, we know that

$$\frac{P_i}{P_o} = \frac{A_o}{A_i}$$

or $$\frac{150 \times 10^5}{50 \times 10^5} = \frac{A_o}{0.02}$$

or $$A_o = 0.06 \text{ m}^2 = \frac{\pi}{4} D_o^2$$

or $$\left.\begin{array}{c}\text{Diameter of}\\ \text{larger cylinder}\end{array}\right\}, D_o = \mathbf{0.2764\ m \ \text{or}\ 276.4\ mm} \quad \textbf{Ans.}$$

8.14. PRESSURE INTENSIFIER CIRCUITS

8.14.1. Intensifier Circuit in Punching Press Application

As we know, usually a heavy punching press requires two pumps (a low-pressure pump and a high-pressure pump) to obtain the high-pressure outlet flow required for the operation. But with the use of a pressure intensifier, one can eliminate the expensive high-pressure pump in the punching press application.

8.14.1.1. Circuit

Fig.8.17 shows a basic hydraulic circuit employing an intensifier for use in a punching operation. This circuit consists of a low-pressure pump, 4/3 DC valve, pilot check valve, sequence valve, pressure intensifier, and cylinder. As shown in Fig.8.17, the intensifier should be installed closer to the cylinder to shorten the high-pressure lines.

8.14.1.2. Operation

First operator places workpiece in fixture and shifts handle of 4/2 DC valve. When the 4/2 DC valve is shifted to the right side position, the oil flows to the blind end of the cylinder through the check valve. When the pressure in the cylinder reaches the sequence valve pressure setting, the sequence valve opens and supplies the flow to the intensifier. Now the intensifier starts to operate and gives high-pressure output. This high-pressure output of the intensifier closes the pilot check valve and pressurizes the blind end of the cylinder to perform the punching operation.

When the 4/2 DC valve is shifted to the left side position, the oil flows to the rod end of the cylinder. When it builds-up the pressure, the pilot signal opens the check valve. Thus the cylinder is retracted to the starting position.

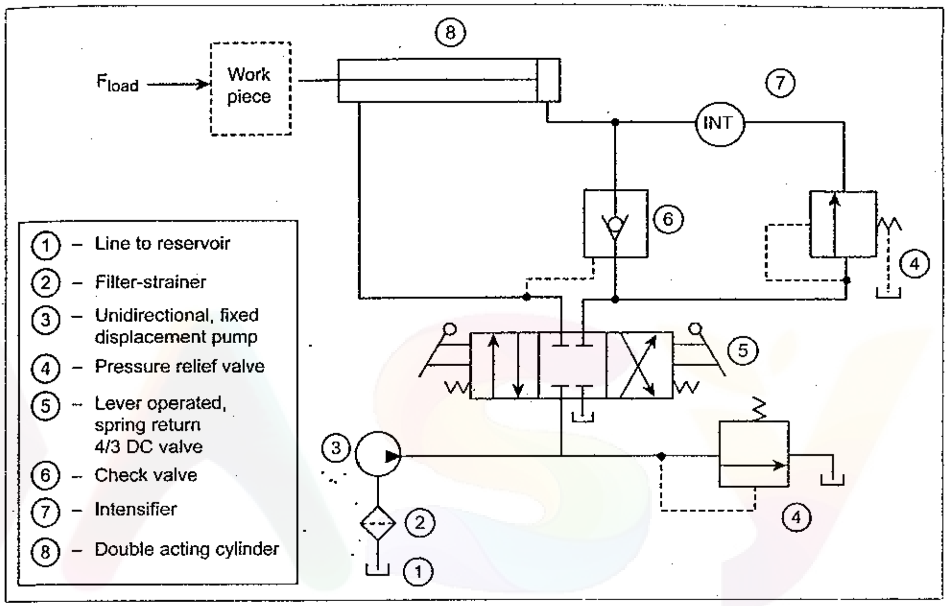

⑧
F_load
Work piece
⑦
INT
⑥
④
⑤
③
②
①
④
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Lever operated, spring return 4/3 DC valve
⑥ – Check valve
⑦ – Intensifier
⑧ – Double acting cylinder

Fig. 8.17. Pressure intensifier circuit

8.14.2. Air-Over-Oil Intensifier Circuit

- ✓ In some applications, the hydraulic and pneumatic circuits are coupled to best use of the advantages of both oil and air mediums.
- ✓ This combination circuit is also known as ***hydro-pneumatic*** or ***pneumo-hydraulic circuits*** or ***dual pressure systems.***

8.14.2.1. Circuit

Fig.8.18 shows a typical air-over-oil intensifier. This circuit can be used for drawing a cylinder over a large distance at a low pressure and then over a small distance at high pressure (such as in punch press applications). This circuit consists two lines—air lines and oil lines. In the circuit, the air lines are shown by single lines and oil lines by double lines.

8.14.2.2. Operation

Extension : When the first 4/2 DC valve (valve 1) is shifted to left mode, the air from the reservoir flows to the approach tank. In the approach tank, the air forces the oil to the blind end of the cylinder through the bottom of the intensifier, as shown by double lines in Fig.8.18. Now the cylinder extends.

Useful Work : When the cylinder experiences its load, the second 4/2 DC valve (valve 2) is actuated to the left mode. This valve position sends air to the top end of the intensifier.

Now the intensifier moves down, and the piston of the intensifier blocks the path of oil from the approach tank. Now the cylinder receives high pressure oil at the blind end to perform the useful work such as punching operation.

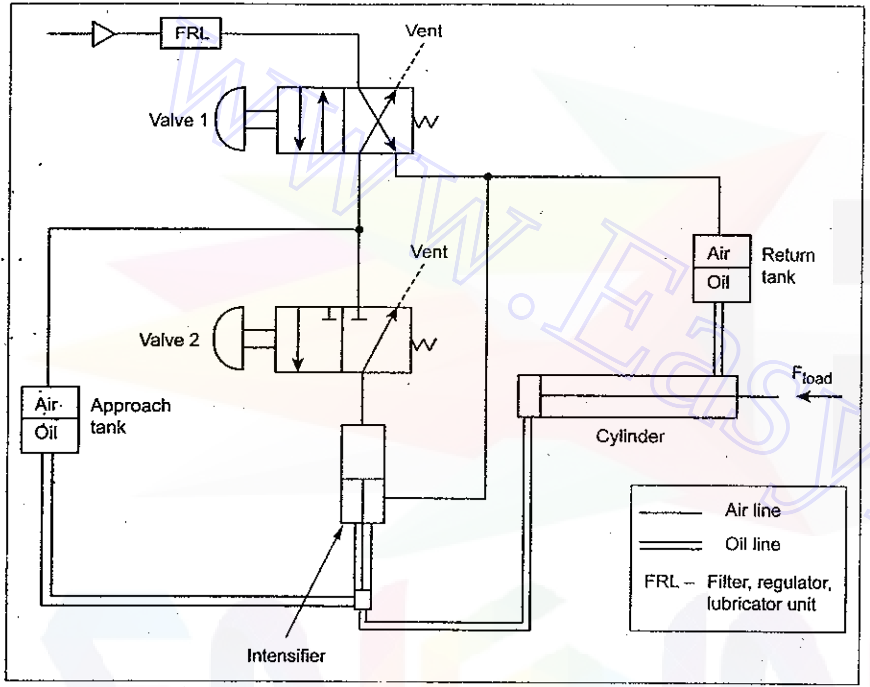


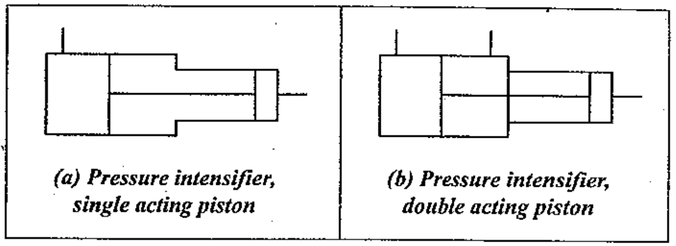
Fig. 8.18. Air-over-oil intensifier circuit

Retraction : When the valve 2 is released (shifted to right mode), the air flow from the reservoir is blocked. The air from the top end of the intensifier is vented to the atmosphere. This completes the high pressure portion of the cycle.

When valve 1 is released (*i.e.*, shifted to right mode), the air flow is diverted to return tank and also the air in the approach tank is vented. The diverted air flow pushes the oil to the rod end of the cylinder. This causes the cylinder to retract. The oil from the piston end of the cylinder is diverted back to the approach tank through the bottom end of the intensifier. This completes the entire cycle of operation.

8.14.3. Graphic Symbol

Fig.8.19(*a*) and (*b*) show the symbolic representation of a pressure intensifier having single and double acting piston respectively.



(a) Pressure intensifier, single acting piston

(b) Pressure intensifier, double acting piston

Fig. 8.19. Graphic symbol for a pressure intensifier

REVIEW AND SUMMARY

✓ *Some of the important ancillary equipment used in the hydraulic system are :*

1. *Fluid reservoir,*
2. *Filters and strainers,*
3. *Heat exchangers,*
4. *Accumulators,*
5. *Intensifiers,*
6. *Pressure gauges,*
7. *Pressure and temperature switches,*
8. *Shock absorbers, and*
9. *Hydraulic piping.*

✓ ***An accumulator*** *is basically a pressure storage reservoir in which a non-compressible hydraulic fluid is retained under pressure from an external source.*

✓ ***Types of accumulators :*** *The three basic types are :*

1. *Weight-loaded (or dead-weight) accumulators,*
2. *Spring-loaded accumulators, and*
3. *Gas-loaded accumulators.*
    - *(i) Non-separator type, and*
    - *(ii) Separator type.*
        - *(a) Piston type, (b) Diaphragm type, and (c) Bladder type.*

✓ ***Applications of accumulators :*** *The accumulator circuits are used as :*

(i) Leakage compensator,
(ii) Auxiliary power source,
(iii) Emergency power source,
(iv) Hydraulic shock absorber,
(v) Fluid make-up device,
(vi) Holding device, and
(vii) Lubricant dispenser.

✓ *In this chapter, the purpose, construction, and operation of various types of accumulators and accumulator circuits have been described in detail.*

✓ ***Pressure intensifier,*** *also known as presser booster, is a device which converts a large-volume, low-pressure fluid supply into a proportionately small-volume, high-pressure fluid outlet.*

✓ *Pressure intensifier finds its application at places where a liquid of very high pressure is to be developed from available low pressure. Typical applications include hydraulic presses, riveting machines, and spot-welders.*

✓ *At the end of the chapter, the purpose, construction, and operation of the pressure intensifier and intensifier circuits have been presented.*

✓ ***Formulae Summary :***

1. Sizing of accumulators :

For weight-loaded type accumulators :

$$\text{Capacity} = P \times A \times L$$

For gas-loaded type accumulators :

(i) $P_1 V_1 = P_2 V_2 = P_3 V_3$

(ii) $\left\{\begin{matrix}\text{Size or total volume}\\ \text{of the accumulator}\end{matrix}\right\} = \left\{\begin{matrix}\text{Volume of the}\\ \text{compressed}\\ \text{gas supplied}\end{matrix}\right\} + \left\{\begin{matrix}\text{Volume of the liquid}\\ \text{required by the system}\end{matrix}\right\}$

(iii) $kW_{pump} = \dfrac{P\ (\text{N/m}^2) \times Q\ (\text{m}^3/\text{s})}{1000}$

2. For pressure intensifiers :

$$\text{Intensifier ratio, } \frac{P_i}{P_o} = \frac{A_o}{A_i} = \frac{Q_{in}}{Q_{out}}$$

KEY TERMS ONE SHOULD REMEMBER

- **Ancillary equipment**
- **Fluid reservoir**
- **Filters**
- **Strainers**
- **Heat exchangers**
- **Pressure gauges**
- **Pressure switches**
- **Temperature switches**
- **Shock absorbers**
- **Hydraulic piping**
- **Accumulators**
  - **Weight-loaded type**
  - **Spring-loaded type**
  - **Gas-loaded type**
- **Non-separator accumulators**
- **Separator accumulators**
  - **Piston-type**
  - **Diaphragm type**
  - **Bladder type**
- **Accumulator symbols**
- **Accumulator circuits**
- **Sizing of accumulators**
- **Capacity of accumulators**
- **Intensifiers**
- **Pressure boosters**
- **Intensifier ratio**
- **Intensifier circuits**
- **Air-over-oil intensifier circuits**
- **Intensifier symbols**

REVIEW QUESTIONS

Short Answer Type Questions

On Ancillary Equipment

1. Name any four ancillary equipment commonly used in the hydraulic system.
2. What is the purpose of a fluid reservoir ?
3. What is the difference between a filter and strainer ?
4. What is the purpose of a heat exchanger ?
5. Why is pressure measurement considered as a crucial process in the hydraulic system ?
6. What is the use of pressure switch ?

7. What is a temperature switch ?
8. What is the use of a shock absorber in a hydraulic system ?

On Accumulators

9. What is the function of an accumulator ? What electrical device is it analogous to ?
10. What are the three basic types of accumulators used in hydraulic systems ?
11. List any five applications of accumulators.
12. What will cause failure of a dead-weight type accumulator ?
13. Which type of accumulator operates at constant pressure ?
14. What type of gas is used in a gas-loaded accumulator ? Why is oxygen not used for this purpose ?
15. Why are non-separator type gas-loaded accumulator not preferred in hydraulic systems ?
16. What is meant by the term 'capacity' of an accumulator ?
17. What are three significant accumulator operating conditions ?

On Intensifiers

18. What is the function of a pressure intensifier ? What electrical device is it analogous to ?
19. Define the term intensifier ratio.
20. What condition in a hydraulic system would require an intensifier ?
21. List any four applications of intensifiers.
22. Draw fluid power symbol for pressure intensifier, and gas-loaded type accumulator.

Essay Answer Type Questions

On Accumulators

1. (*a*) What is an accumulator ? What are its functions ?
   (*b*) State various types of accumulators.
   (*c*) Compare a dead-weight type accumulator with a spring-loaded type accumulator, explaining their merits and demerits.
2. (*a*) Explain how a non-separator type accumulator works.
   (*b*) List out the drawbacks that limit their use in hydraulic systems.
3. (*a*) What is the difference between a non-separator type and separator type accumulators ?
   (*b*) Name the three types of the separator accumulator. Give one advantage and disadvantage of each type.
4. With a neat sketch, explain the construction and operation of a piston-type accumulator.
5. What is a diaphragm-type accumulator ? Explain its working with a sketch. Also bring out its merits and demerits.
6. (*a*) What is a bladder type accumulator ? With a neat sketch, explain the construction and operation of it.
   (*b*) Compare the various parameters of three types of separator accumulators.

7. Explain with suitable circuits, how an accumulator can be used as :
   (*i*) a leakage compensator, and
   (*ii*) an emergency power source.
8. Make a circuit sketch showing the use of an accumulator as :
   (*i*) a secondary power source, and
   (*ii*) a hydraulic shock absorber.

On Intensifiers

9. (*a*) What is the function of a hydraulic intensifier ?
   (*b*) Explain the construction and operation of a pressure booster, with a neat sketch.
   (*c*) Make a list of applications where intensifiers are employed ?
10. (*a*) Make a circuit sketch showing an intensifier in a punching press application.
   (*b*) What is meant by an air-over-oil system ? Explain the operation of the air-over-oil intensifier circuit.

PROBLEMS FOR PRACTICE

On Accumulators

1. An accumulator has a ram of 150 mm diameter and a lift of 5 m. If the oil is supplied at 50 bar, find the necessary load on the ram, and capacity of the accumulator.
   [*Ans.* 88.36 kN ; 441.79 kN-m]
2. What is the size of accumulator necessary to supply 2000 cm^3 of oil with an allowable pressure drop from 22 MPa to 16 MPa. The precharge pressure is 13 Mpa. Take charging and discharging processes as isothermal. [*Ans.* 9025.64 cm^3 or 9.02 L]
3. The car crushing system is to be designed. The crushing force requirement is such that a 0.20 m diameter hydraulic cylinder is required at a working pressure of 1.3 × 10^7 N/m^2. Time for crushing is about 10 seconds and the stroke required to flatten the car is 2.5 m. Compare the power requirement of a circuit without accumulator and with accumulator. Accumulator details :
   Time taken for charging of accumulator = 5 min ;
   Initial pressure of charging (uncharged), $P_1 = 0.8 \times 10^7$ N/m^2 ;
   Charge pressure of accumulator, $P_2 = 2.4 \times 10^7$ N/m^2 ;
   Minimum pressure for crushing, $P_3 = 1.3 \times 10^7$ N/m^2.
   [*Ans.* $(\text{kW}_{pump})_{with\ accumulator} = 12.56$ kW, and
   $(\text{kW}_{pump})_{without\ accumulator} = 102.1$ kW]

On Intensifiers

4. If an intensifier has an input pressure of 105 bar and the area of the input piston is 65 cm^2, what would be the output pressure if the output ram has an area of 10 cm^2 ?
   [*Ans.* 682.5 bar]
5. A hydraulic intensifier gets the low pressure liquid at a pressure of 40 bar and delivers it to a machine at a pressure of 160 bar. If the intensifier has a capacity of 0.021 m^3 and stroke 1.2 m, determine the diameters of the fixed ram and the sliding cylinder to be used for this intensifier. [*Ans.* 149 mm, 298 mm]

□□

Chapter 9

Electrical Controls for Fluid Power Systems

"Always design a thing by considering it in its next larger context—a chair in a room, a room in a house, a house in an environment in a city plan."
—Eliel Soorinen

"In wisdom gathered over time I have found that every experience is a form of exploration."
—Ansel Adams

"Weakness of attitude becomes weakness of character."
—Albert Einstein

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Identify and understand the function of the various electrical control devices used in the fluid power systems.

☑ Explain the operating principle of an electrically operated relay switch used in an electrohydraulic system.

☑ Understand and construct the electrical ladder diagrams.

☑ Interrelate the operation of electrical ladder diagrams with the corresponding hydraulic circuits.

CHAPTER 9

ELECTRICAL CONTROLS FOR FLUID POWER SYSTEMS

9.1. INTRODUCTION

Nowadays, the focus has been shifted from manual control to electrical control of fluid power systems. The electrical control devices are widely preferred because of the following reasons :

(*i*) They can be easily controlled.

(*ii*) They improve the overall control flexibility of fluid power systems.

(*iii*) They provide quick and accurate control operations.

(*iv*) They require less maintenance.

(*v*) They exhibit better reliability and have longer service life.

In addition, the complete automation requires the electrical signals (from computer interfaces) to control the machines.

In this chapter, we shall identify and understand the various electrical components used in the control of fluid power. Also we shall explain how these components are used in various ladder diagrams.

9.2. TYPES OF ELECTRICAL CONTROL DEVICES

The most commonly used electrical control devices are :

1. Push-button switches,
2. Limit switches,
3. Pressure switches,
4. Temperature switches,
5. Solenoids,
6. Relays, and
7. Timers.

9.2.1. Push-button Switches

✓ The push-button switches are primarily used for starting and stopping of the machinery. They also provide manual operation when an emergency arises.

✓ The push-button switches are also called as ***'momentary switches'***, because they make or break contact only as long as they are held under pressure.

✓ ***Types :*** The four commonly used types of push-button switches are :

(*i*) Single-pole single-throw – Normally open type (SPST–NO),

(*ii*) Single-pole single-throw – Normally close type (SPST–NC), (*iii*) Double-pole single-throw type (DPST), and

(*iv*) Double-pole double-throw type (DPDT).

Fig.9.1 shows the symbolic representation for the above types of push-button switches.

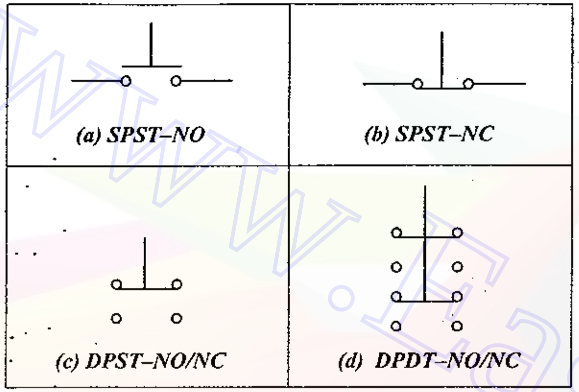
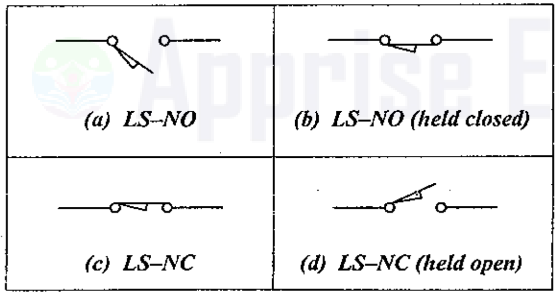

(a) SPST–NO (b) SPST–NC (c) DPST–NO/NC (d) DPDT–NO/NC

Fig. 9.1. Graphic symbols for push-button switches

- ✓ As shown in Figs.9.1 (*a*) and (*b*), the single-pole single-throw type has one normally open and one normally closed pair of contacts.
- ✓ As shown in Figs.9.1 (*c*) and (*d*), the double-pole double-throw arrangement has two pairs of normally open and two pairs of normally closed contacts to allow the inverting of two circuits with single input.

9.2.2. Limit Switches

- ✓ The limit switches are used to identify the extreme limits of the cylinder actuation.
- ✓ ***Difference :*** The difference between the push-button and limit switches is that the push-button switches are actuated manually whereas the limit switches are mechanically actuated devices.
- ✓ ***Types :*** Fig.9.2 shows the graphic symbols for the commonly used limit switches.


(a) LS–NO (b) LS–NO (held closed) (c) LS–NC (d) LS–NC (held open)

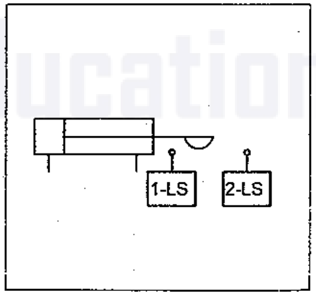


Fig. 9.2. Graphic symbols for limit switches *Fig. 9.3. Cylinder with built-in limit switches*

- ✓ In Fig.9.2(*a*), LS-NO means a limit-switch normally-open. Fig.9.2(*b*) shows a normally open limit-switch that is held closed. In Fig.9.2(*c*), LS-NC means a limit-switch normally-closed. Fig.9.2(*d*) shows a normally closed type limit-switch that is held open.
- ✓ Fig.9.3 shows a hydraulic cylinder that has built-in limit switches, one at each end of the cylinder.
- ✓ There are many operators available such as cams, levers, rollers, and plungers to mechanically actuate the limit switches.

9.2.3. Pressure Switches

- ✓ As discussed in Section 8.1, the pressure switches are used to sense a change in pressure automatically, and opens or closes an electrical switch when a predetermined pressure is reached.
- ✓ They have usually two pressure settings, namely high and low pressure. For example, in a circuit it may be required to stop a pump to maintain a given pressure. In this circuit, the low-pressure setting will start the pump and the high-pressure setting will stop the pump.
- ✓ Fig.9.4 shows the graphic symbols used for pressure switches.

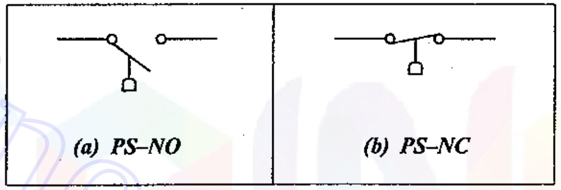

(a) PS–NO (b) PS–NC

Fig. 9.4. Graphic symbols for pressure switches

- ✓ Fig.9.4(*a*) shows a normally open pressure switch, which is abbreviated PS-NO. Fig.9.4(*b*) depicts a pressure switch which is normally closed.

9.2.4. Temperature Switches

- ✓ As discussed in Section 8.1, the temperature switches are used to sense a change in temperature automatically, and opens or closes an electrical switch when a predetermined temperature is reached.
- ✓ Like other switches, these switches are also wired either normally open or normally closed.
- ✓ Fig.9.5 shows the graphic symbols used for temperature switches.
- ✓ Fig.9.5(*a*) shows a normally open type temperature switch and Fig.9.5(*b*) shows the normally closed type.

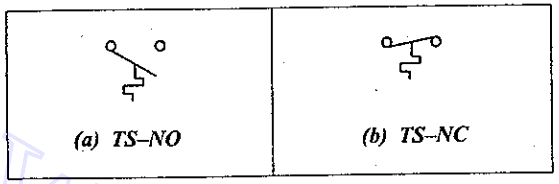


Fig. 9.5. Graphic symbols for temperature switches

9.2.5. Solenoids

- ✓ As discussed in Section 7.8.4, a solenoid is an electromagnetic mechanical transducer that converts an electrical signal into a mechanical output force.
- ✓ Solenoids provide a push or pull force to remotely operate fluid power valves.
- ✓ Fig.9.6(*a*) shows the graphical symbol used to represent the solenoid.

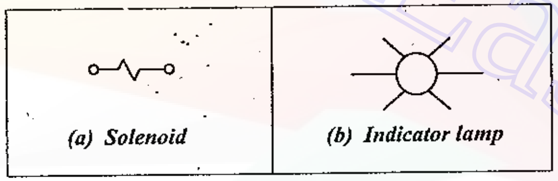


Fig. 9.6. Graphic symbols for solenoid and indicator lamp

- ✓ ***An indicator lamp*** is used to indicate the state of a specific circuit components.
- ✓ Indicator lamps are used :
  - (*i*) to identify which solenoid operator of a DC valve is energized, and
  - (*ii*) to indicate whether a hydraulic cylinder is extending or retracting.
- ✓ Fig.9.6(*b*) shows the symbolic representation of an indicator lamp.

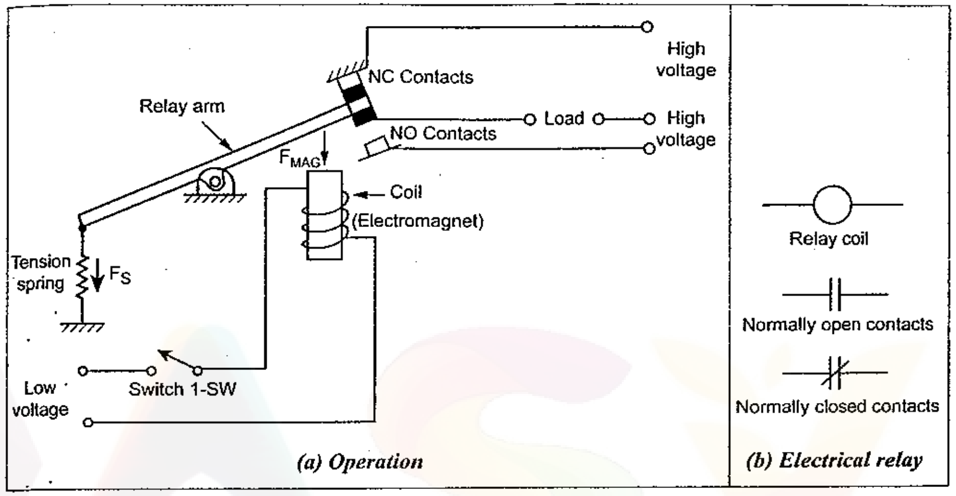
9.2.6. Relays

9.2.6.1. What are Relays ?

- ✓ The electrical relays offer simple ON/OFF switching action in response to a signal issued by a control system.
- ✓ In other words, relays are nothing but electrically operated switches.
- ✓ Relays are commonly used to open or close the contacts and thereby energize or de-energize solenoids which operate at a high current level. A low-voltage circuit can be used to energize relay coils that control high-voltage contacts used to open and close circuits containing the solenoids.

9.2.6.2. Operating Principle

Fig.9.7(*a*) illustrates the operating principle of an electrically operated relay switch.



(a) Operation (b) Electrical relay

Fig. 9.7. Electrical relay

When switch 1–SW is closed, the current flows through the coil of wire and thus a magnetic field is produced. This pulls a spring-loaded moveable relay arm that forces the contacts to open or close. Usually there are two sets of contacts with upper one being normally closed (NC) contacts, and the lower one is normally open (NO) contacts.

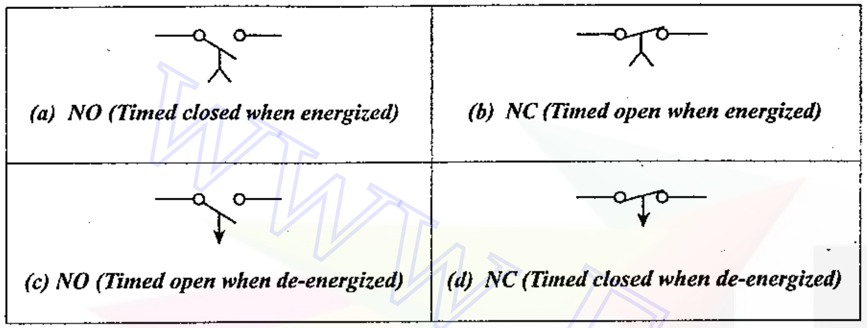
9.2.6.3. Graphic Symbols

Fig.9.7(*b*) shows the graphical symbols for the relay coil and the symbols for the normally open and closed contacts.

9.2.7. Timers

- ✓ Timers, also known as ***time-delay relays,*** are time delay switches used to control the time duration of a working cycle.
- ✓ Timers are commonly applied in electrical control circuits when a time delay from the instant of actuation to the closing of contacts is required.
- ✓ These timers can be adjusted to change the dwell period for many machining operations. For example, in a drilling machine operation the timers provide a dwell, which allows the drill to pause for a predetermined time at the end of the stroke to remove the chips.
- ✓ The symbolic representation of the timers is shown in Fig.9.8.
- ✓ Fig.9.8(*a*) shows a normally open switch when energized closes after a predetermined time interval. Fig.9.8(*b*) shows a normally closed timer switch that is time opened when energized. Fig.9.8(*c*) shows the normally open timer switch that is timed when

de-energized. Fig.9.8(*d*) shows the normally closed timer switch that is time closed when de-energized.


(a) NO (Timed closed when energized)

(b) NC (Timed open when energized)

(c) NO (Timed open when de-energized)

(d) NC (Timed closed when de-energized)

Fig. 9.8. Electrical timer symbols

9.3. LADDER DIAGRAMS

9.3.1. Introduction

It should be noted that while drawing any electrohydraulic (or electropneumatic) circuits, separate circuits should be drawn for the fluid system and the electrical system. Also each components should be labeled so that one can understand exactly how the two systems interfaced. The second circuit showing the electrical system is known as ladder diagram. Thus the operation of the total system can be understood by examination of both the fluid power circuit and ladder diagram (*i.e.*, electrical circuit).

9.3.2. What is Meant by a Ladder Diagram ?

- ✓ A ladder diagram is a representation of hardware connections between switches, relays, solenoids, *etc.*, which constitute the basic components of an electrical control system.
- ✓ In other words, *a ladder diagram is nothing but an electrical diagram showing the hardware connections between the various electrical control devices.*

9.3.3. Details of a Ladder Diagram

Consider a typical ladder diagram as shown in Fig.9.9 for some application.

- ✓ ***Legs and Rungs :*** In Fig.9.9, the two vertical electrical power supply lines are called 'legs', and the horizontal lines containing electrical components are called 'rungs'.
- ✓ In ladder diagrams, always the power is connected to the left leg and the ground is connected to the right leg.
- ✓ It should be noted that always the switches should be shown in their unactuated (*i.e.*, open) mode in the ladder diagrams.

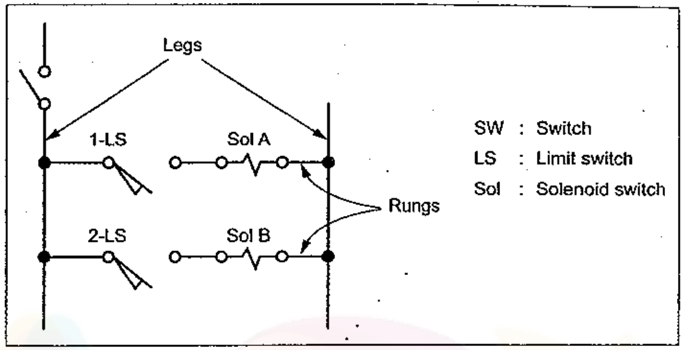


Fig. 9.9. Typical ladder diagram

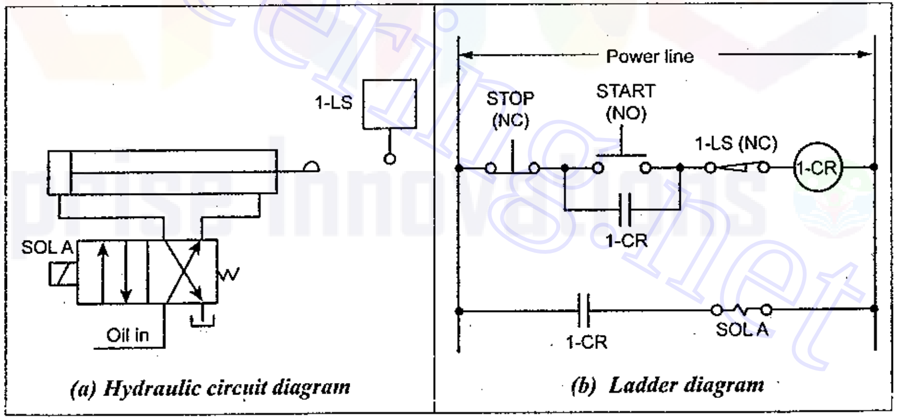
- ✓ *Since the electric circuit diagram resembles to a ladder, this diagram is called a 'ladder diagram'.*
- ✓ ***Uses :*** Ladder diagrams provide a circuit designer with a practical means to examine input process and output functions to quickly plan the circuit layout design for a particular hydraulic or pneumatic application.

Now we shall illustrate some important electrohydraulic circuits with the use of ladder diagrams.

9.4. CONTROL OF A CYLINDER USING A SINGLE LIMIT SWITCH

9.4.1. Circuits and Construction

An electrohydraulic system which uses a single solenoid valve and a single limit switch to control a double-acting hydraulic cylinder is illustrated in Fig.9.10.



(a) Hydraulic circuit diagram

(b) Ladder diagram

Fig. 9.10. Control of hydraulic cylinder using single limit switch

Fig.9.10(*a*) shows the hydraulic circuit diagram and Fig.9.10(*b*) shows the electrical circuit diagram, also known as the ladder diagram.

The hydraulic circuit [Fig.9.10(*a*)] consists of a single solenoid valve (which is labeled as SOL A) and a single limit switch (which is labeled as 1-LS). The ladder diagram [Fig.9.10(*b*)] use one relay with a coil (designated as 1-CR) and two separate, normally open sets of contacts [labeled as 1-CR (NO)]. Also two push-button switches, one normally closed (labelled STOP) and one normally opened (labelled START) are included.

9.4.2. Operation

The sequence of operation is as follows :

Extension Stroke

1. When the START push-button switch is pressed momentarily, the relay coil 1-CR gets energized which closes both sets of contacts of 1-CR.
2. The upper 1-CR set of contacts serves to keep coil 1-CR energized even though the START push-button switch is released.
3. The lower 1-CR set of contacts closes to energize solenoid A to extend the cylinder.

Retraction Stroke

4. When the extension stroke of the piston reaches its end, the piston rod cam actuates 1-LS (NC). Now the 1-LS opens to de-energize coil 1-CR.
5. The de-energisation of coil 1-CR reopens the contacts of 1-CR to deenergize solenoid A. This returns the valve to its spring offset mode and the cylinder retracts.

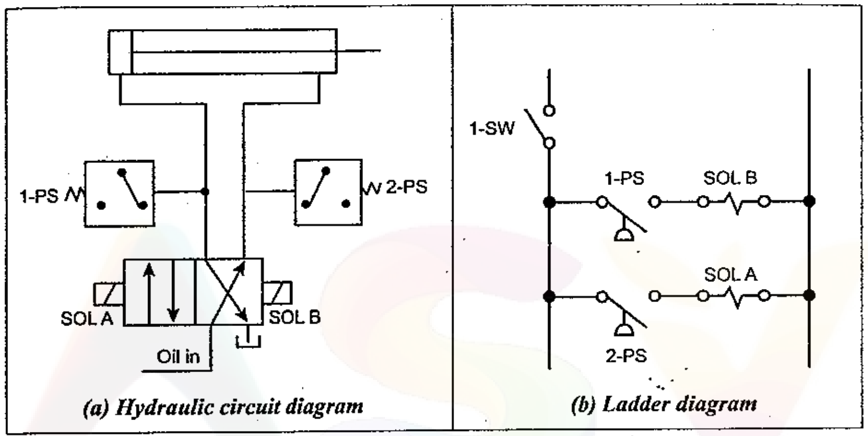
Cycle of Operation

6. The retraction of cylinder again closes the contacts of 1-LS but coil 1-CR is not energized because the START push-button switch and upper 1-CR contacts have returned back to their normally open position. Thus the cylinder stops at the end of the retraction stroke.
7. The cycle of operation can be repeated by pressing the START push-button switch manually. The STOP button is actually an emergency button and whenever it is pressed, it will immediately stop the extension stroke and fully retracts the cylinder back.

9.5. RECIPROCATION OF A CYLINDER USING PRESSURE SWITCHES

9.5.1. Circuit and Construction

Fig.9.11 shows how two pressure switches can be used to control the operation of a double-acting hydraulic cylinder. Fig.9.11(*a*) shows the hydraulic circuit diagram and Fig.9.11(*b*) shows its ladder diagram. In Fig.9.11(*b*), as long as switch 1–SW is closed, the cylinder reciprocates continuously.



(a) Hydraulic circuit diagram *(b) Ladder diagram*

Fig. 9.11. Reciprocation of cylinder using pressure switches

9.5.2. Operation

The sequence of operation is as follows :

Extension stroke

1. When solenoid SOL A is energized, the 4/2 DC valve is shifted to left mode and it forces the oil to flow into the blind end of the cylinder. Thus the cylinder extends.
2. When the cylinder is extended to its maximum stroke, the pressure builds up to actuate pressure switch 1–PS. This energises the solenoid SOL B, as could be seen from Fig.9.11(*b*).

Retraction stroke

3. When the solenoid SOL B is energised, the 4/2 DC valve is shifted to right mode and it forces the oil to flow into the rod end of the cylinder. Thus the cylinder retracts.
4. When the cylinder is fully retracted to its left, the pressure builds up to actuate pressure switch 2–PS. During retraction period, pressure switch 1–PS has been de-actuated to de-energise SOL B.

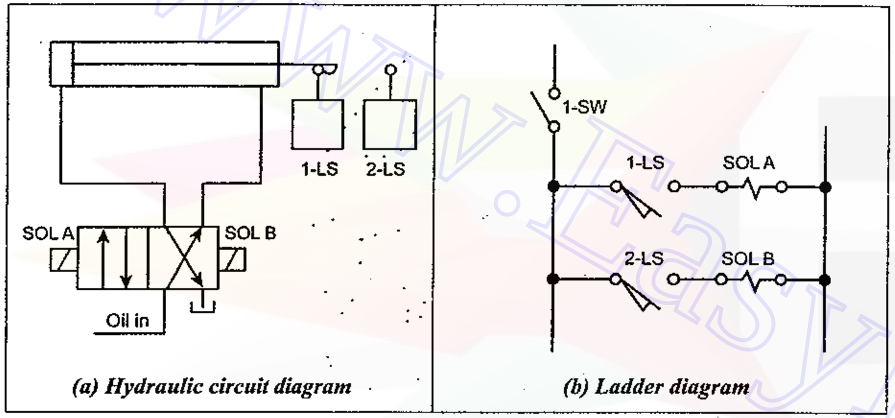
Cycle of operation

5. The closing of the contacts of 2–PS energizes SOL A to once again begin the extending stroke of the cylinder. Thus the cycle of operation can be repeated again and again.

9.6. RECIPROCATION OF A CYLINDER USING LIMIT SWITCHES

9.6.1. Circuits and Construction

Fig.9.12 shows how limit switches can be substituted for pressure switches to control the operation of a double-acting hydraulic cylinder. Figs.9.12(*a*) and (*b*) show its corresponding hydraulic and electric circuit diagrams respectively.



(a) Hydraulic circuit diagram *(b) Ladder diagram*

Fig. 9.12. Reciprocation of cylinder using limit switches

9.6.2. Operation

The sequence of operation and control capability are exactly the same as that of the system discussed in Section 9.5.2, except that each pressure switch is replaced by a normally open limit switch.

9.7. DUAL-CYLINDER SEQUENCING CIRCUIT

9.7.1. Circuits and Construction

Fig.9.13 illustrates a electrohydraulic system that provides a cycle sequence of two hydraulic cylinders. Fig.9.13(*a*) shows the hydraulic circuit of the system and Fig.9.13(*b*) shows its ladder diagram. This system uses two sequence valves V_1 and V_2 to control the sequence of operations of two double-acting cylinders.

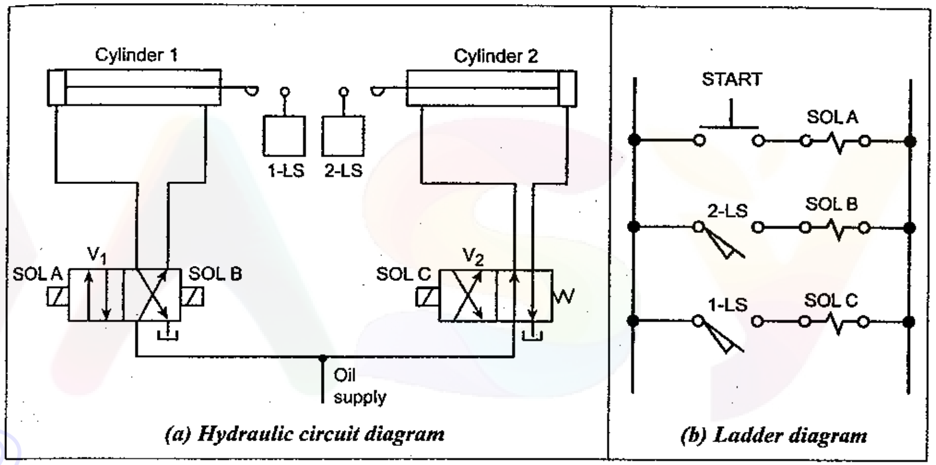
9.7.2. Operation

The sequence of operation is as follows :

Extension stroke

1. When the START push-button switch is momentarily pressed, solenoid SOL A is energized.

2. When the SOL A is energized, the 4/2 DC valve V_1 is shifted to left mode and it forces the oil to flow into the blind end of the cylinder 1. Thus, the cylinder 1 extends.
3. When limit switch 1–LS is actuated, solenoid SOL C is energized.
4. When the SOL C is energised, the 4/2 DC valve V_2 is shifted to left mode and it forces the oil to flow into the blind end of the cylinder 2. Thus, the cylinder 2 extends.



(a) Hydraulic circuit diagram *(b) Ladder diagram*

Fig. 9.13. Dual-cylinder sequencing circuit

Retraction stroke

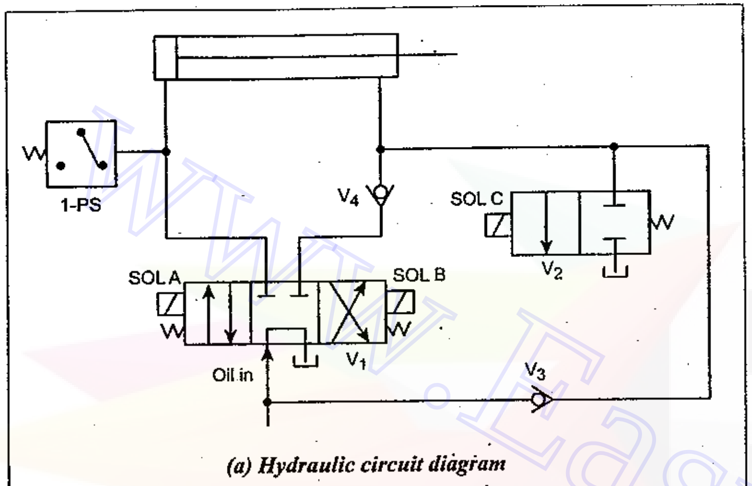
5. When limit switch 2–LS is actuated, solenoid SOL B is energized.
6. When the SOL B is energized, the valve V_1 is shifted to right mode and it forces the oil to flow into the rod end of the cylinder 1. So the cylinder 1 starts to retract.
7. As the cylinder 1 starts to retract, it deactuates the limit switch 1–LS, which de-energizes SOL C.
8. When the SOL C is de-energised, the valve V_2 is shifted to spring offset mode. This forces the piston of the cylinder 2 to retract to its original position.
9. As a result, both cylinders 1 and 2 retract at the same time, and thus a cycle of operation is completed.

9.8. REGENERATIVE CIRCUIT

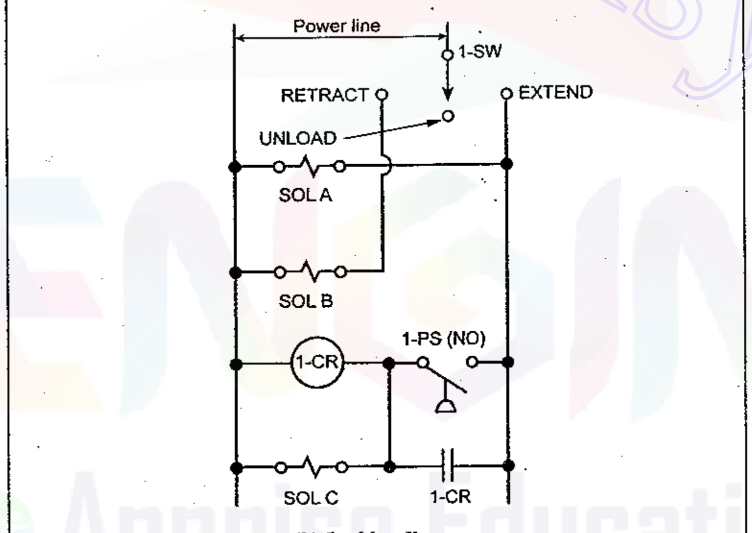
A regenerative circuit is commonly used to speed up the extending speed of a double-acting hydraulic cylinder.

9.8.1. Circuits and Construction

Fig.9.14 illustrates an electrical control of a regenerative cylinder. Fig.9.14(*a*) shows the hydraulic circuit of the system and Fig.9.14(*b*) shows its ladder diagram.



(a) Hydraulic circuit diagram



(b) Ladder diagram

Fig. 9.14. Electrical control of regenerative circuit

9.8.2. Operation

The sequence of operation is as follows :

Extension stroke

1. First switch 1–SW is manually shifted into the 'EXTEND' position, as shown in Fig.9.14(*b*).

2. When switch 1–SW is shifted to 'EXTEND' position, the solenoid SOL A is energized. This shifts the 4/3 DC valve V_1 to the right mode and it forces the oil to flow into the blind end of the cylinder. Thus the cylinder extends.
3. Now the oil from the rod end of the cylinder passes through check valve V_3 to join the incoming oil from the pump. This oil addition facilitates rapid cylinder extension.
4. When oil pressure builds up due to intended loadings on the cylinder, it actuates a normally open pressure switch 1–PS. This energizes both coil 1–CR and SOL C.
5. When the SOL C is energized, the 3/2 DC valve V_2 is shifted to the left mode and it directs the oil from the rod end of the cylinder to the oil tank. Thus the cylinder extends slowly when it is loaded.

Retraction stroke

6. When switch 1–SW is manually shifted into the 'RETRACT' position [Fig.9.14(*b*)], the solenoid SOL B is energized. This shifts the 4/3 DC valve V_1 to the left mode and it forces the oil to flow into the rod end of the cylinder. Thus the cylinder fully retracts.
7. When the switch 1–SW is manually shifted to the 'UNLOAD' position [Fig.9.14(*b*)], all the solenoids and the relay coil are de-energized. At this time, the valve V_1 is in its spring centered to unload the pump.

REVIEW AND SUMMARY

✓ *The electrical control devices are widely used to improve the overall control flexibility of fluid power systems.*

✓ ***Types :*** *The most commonly used electrical control devices are :*

1. *Push-button switches,*
2. *Limit switches,*
3. *Pressure switches,*
4. *Temperature switches,*
5. *Solenoids,*
6. *Relays, and*
7. *Timers.*

✓ *The **push-button switches** are mainly used for starting and stopping of the machinery. They also provide manual operation when an emergency arises.*

✓ *The **limit switches** are used to identify the extreme limits of the cylinder actuation.*

✓ *The **pressure switches** are used to sense a change in pressure automatically, and opens or closes an electrical switch when a predetermined pressure is reached.*

✓ *The **temperature switches** are used to sense a change in temperature automatically, and opens or closes an electrical switch when a predetermined temperature is reached.*

✓ *A **solenoid** is an electromagnetic mechanical transducer that converts an electrical signal into a mechanical output force.*

- ✓ ***An indicator lamp** is used to indicate the state of a specific circuit component.*
- ✓ ***Relays** are commonly used to open to close the contacts and thereby energize or de-energize solenoids.*
- ✓ ***Timers** are time delay switches used to control the time duration of a working cycle.*
- ✓ ***A ladder diagram** is a representation of hardware connections between switches, relays, solenoids, etc., which constitute the basic components of an electrical control system.*
- ✓ *At the end of the chapter, the various electrohydraulic circuits have been analyzed with the help of ladder diagrams.*

KEY TERMS ONE SHOULD REMEMBER

Electrical control devices
Push-button switches
  SPST–NO
  SPST–NC
  DPST–NO/NC
  DPDT–NO/NC
Momentary switches
Limit switches
  LS–NO
  LS–NC

Pressure switches
  PS–NO
  PS–NC
Temperature switches
  TS–NO
  TS–NC
Solenoids
Indicator lamp
Relays
Timers

Time-delay relays
Ladder diagram
Legs
Rungs
Electrohydraulic circuits
Dual-cylinder sequencing circuit
Regenerate circuit

REVIEW QUESTIONS

Short Answer Type Questions

1. Why are electrical controls of fluid power systems preferred than the manual controls ?
2. Name any four basic electrical devices commonly used in the control of fluid power systems.
3. What is the use of a push-button switch ?
4. What are the four types of push-button switches ? Also draw their graphic symbols.
5. What are limit switches ? How do they differ from push-button switches ?
6. Draw the graphic symbols for representing limit switches.
7. What is the purpose of a pressure switch ? Also draw its graphic symbol.
8. What is the use of a temperature switch ? Also draw its graphic symbol.
9. What is a solenoid ? Also state its use.
10. What is the purpose of having an indicator lamp in an electric circuit of a fluid power system ?

11. What do you mean by an electrical relay ?
12. What is the purpose of a timer ?
13. Explain one situation where you use an electrical timer.
14. Draw the graphic symbols for the following :
    (*a*) Solenoid, (*b*) Indicator lamp,
    (*c*) Relay, and (*d*) Timer.
15. What is a ladder diagram ?
16. What are the uses of a ladder diagram ?

Essay Answer Type Questions

1. What is meant by an electrical relay ? With neat sketch, explain the working principle of an electrical relay.
2. With the use of a ladder diagram, explain how a solenoid valve and a limit switch control the operation of a double-acting hydraulic cylinder.
3. With the help of separate hydraulic and electrical circuit diagram, describe how pressure switches or limit switches can be used to control the operation of a double-acting hydraulic cylinder.
4. Making the ladder diagram, explain a dual-cylinder sequencing circuit.
5. Discuss the ladder diagram connections for a regenerative circuit.

□□

Unit
4

Pneumatic Systems and Components

Chapter 10 : Basics of Pneumatics

Chapter 11 : Air Compressors and Fluid Conditioners

Chapter 12 : Pneumatic Valves and Actuators

Chapter 13 : Fluid Power Circuit Design

Chapter 10

Basics of Pneumatics

"The whole of science is nothing more than a refinement of everyday thinking."
–Albert Einstein

"To measure is to know."
"If you cannot measure it, you cannot improve it."
– Lord Kelvin

"Courage is the first of human qualities because it is the quality which guarantees all others."
–Winston Churchill

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Recognize and explain the advantages and disadvantages of pneumatic systems.

☑ Identify and appreciate the applications of pneumatic systems in various industries/fields.

☑ Describe the various properties desired of a medium (air) in a pneumatic system.

☑ Understand and apply the perfect gas laws to determine the pressure, volume, and temperature of a gas in a pneumatic system.

☑ List the basic components required for a pneumatic system.

CHAPTER 10 BASICS OF PNEUMATICS

10.1. INTRODUCTION

So far we have discussed the hydraulic systems which use hydraulic fluids as the fluid medium to transmit and control power. Now we shall shift our focus on the other branch of fluid power 'pneumatics'. Thus the following chapters of the text is devoted to the study of pneumatic systems.

10.2. PNEUMATICS AND PNEUMATIC SYSTEMS

10.2.1. What does the term 'Pneumatics' refer ?

- ✓ The term 'pneumatics' has been derived from the Greek word 'pneuma', which means air, wind, or breath.
- ✓ ***Definition :*** *The pneumatics may be defined as that branch of engineering-science which deals with the study of the behaviour and application of compressed air.*
- ✓ Like hydraulics, pneumatics is a branch of the fluid power technology. Thus the pneumatics is the technology that deals with the generation, control, and transmission of power using pressurised air.

10.2.2. Pneumatic Systems

- ✓ Pneumatic system is the one that uses a pressurized gas to transmit and control power.
- ✓ However, almost all pneumatic systems prefer to use air rather than some other gas as their fluid medium.
- ✓ The air is popularly used as the fluid medium in pneumatic systems due to the following reasons :
  - (*i*) Air is abundantly available.
  - (*ii*) It is safe to use (as it has the fire-proof characteristics).
  - (*iii*) It is very cheaper in cost.
  - (*iv*) Easier maintenance and easy handling.
  - (*v*) It can be exhausted easily to the atmosphere after use.

10.2.3. Advantages of Pneumatic Systems Over Hydraulic Systems (What are the reasons for considering the use of Pneumatic Systems instead of Hydraulic Systems ?)

In many applications, the pneumatic systems are preferred over the hydraulic systems, due to the following reasons :

1. Since the weight density of gas is many times lesser than liquid, therefore inertia effect of pneumatic components are lesser than hydraulic system components. Thus the force required to accelerate gas (air) is much lesser than that required to accelerate an equal volume of oil.
2. Since viscosity of air is much lesser than that of oil, therefore the pneumatic systems experience lesser frictional pressure and power losses than the hydraulic systems.
3. Unlike in hydraulic systems, pneumatic systems can exhaust its fluid medium (air) to the atmosphere after completing its assigned task. This reduces the requirements of special designs for reservoirs and leak-proof systems.
4. Pneumatic systems are comparatively cheaper in cost than the hydraulic systems.
5. Pneumatic systems provide better operational advantages when compared to hydraulic systems.
6. Compared to hydraulic systems, pneumatic systems are lesser in weight.
7. Unlike in hydraulic systems, leakage of air in pneumatic systems will not affect the system performance very much (because the air compressor supplies the pressurised air continuously).

10.2.4. Disadvantages of Pneumatic Systems

The main disadvantages of pneumatic systems are given below :

1. Due to the high compressibility of air, pneumatic systems cannot provide precise actuator control and precise positioning control.
2. Due to compressor design limitations, pneumatic systems can be applied only to low-pressure (less than 17 bars) applications; whereas hydraulic systems can be applied to high-pressure (upto 700 bars) applications.

10.2.5. Applications of Pneumatic Systems

As discussed in Section 1.5, like hydraulic systems, the application of pneumatic systems can be found in almost all industries/fields. However some of the industrial applications are listed below :

1. Stamping,
2. Drilling,
3. Hoisting,
4. Punching,
5. Assembling,
6. Clamping,
7. Riveting,
8. Materials handling,
9. Logic controlling, and
10. Hammering.

10.2.6. Selection of Hydraulic and Pneumatic Systems

For a given application, there is no hard and fast rule to follow to decide which of the system should be used. However, the following guidelines may be followed for the selection :

1. If the application requires a very high pressure or an extremely accurate feed, then an oil hydraulic system can be used.
2. If the application requires speed, a medium amount of pressure, and only a fairly accurate feed, then an air pneumatic system can be used.
3. If the application requires only a medium amount of pressure and a feed of greater accuracy, then a combination of air and hydraulic systems can be used.

10.3. PROPERTIES OF AIR

10.3.1. What is the Composition of Air ?

✓ Actually speaking, air is a mixture of gases. Air is invisible, colourless, odourless, and tasteless.

✓ ***Composition :*** The main constituents of air by volume are 78% nitrogen, 21% oxygen, and 1% other gases such as argon and carbon dioxide.

✓ The gaseous layer of air around the earth is known as ***atmosphere.***

10.3.2. Pressure Relationship

✓ ***Atmospheric pressure :*** The air surrounding the earth exerts a pressure on the earth's surface. The pressure prevailing directly on the earth's surface is known as atmospheric pressure.

✓ The atmospheric pressure is also referred to as ***reference pressure.*** Normally it considers the sea level as its reference point.

✓ The atmospheric pressure may be calculated from the fundamental principle of barometer which states that the barometer reads the pressure due to the height of mercury (Hg) in the tube and its weight.

$$\therefore \quad \text{Atmospheric pressure} = \rho\, g\, h \qquad \ldots (10.1)$$

where ρ = Density of Hg = 13600 kg/m^3,

g = Acceleration due to gravity = 9.81 m/s^2, and

h = Height of Hg column = 760 mm of Hg at normal sea level.

Substituting the above values in equation (10.1), we get

$$\text{Atmospheric pressure} = 13600 \times 9.81 \times 0.76$$

$$= 1{,}01{,}396 \ \text{N/m}^2 = 1.013 \ \text{bar}$$

But for easy and simple calculation, we take the atmospheric pressure as 1 bar.

✓ ***Absolute and gauge pressure :*** As discussed in Section 4.3.5, the relationship between atmospheric, absolute, and gauge pressures can be given as below :

$$\text{Absolute pressure} = \text{Gauge pressure} + \text{Atmospheric pressure} \qquad \ldots (10.2)$$

$$P_{abs} = P_g + 1.013 \ \text{bar} \qquad \ldots (10.3)$$

- ✓ ***Pressure variation with altitude :*** The atmospheric pressure decreases with the increase in altitude, as shown in Fig.10.1. From Fig.10.1, it may be noted that the pressure varies linearly upto an altitude of 6 km and after that the pressure drops about 11 kPa per km change in altitude.

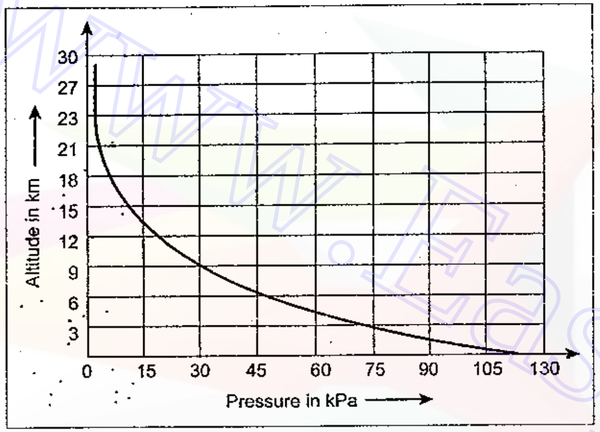


Fig. 10.1. Pressure variation in the atmosphere

- ✓ ***Standard air :*** Standard air is sea-level air having a temperature of 20°C, pressure of 1.013 bar, and a relative humidity[†] of 36%. Usually the above valves of standard air are used while making pneumatic system calculations.

10.3.3. Perfect Gas Laws

We know that, Boyle's law, Charles' law, Gay-Lussac's law and the general gas law are called the 'perfect gas laws' because they were derived on the basis of a perfect gas. The air behaves like a perfect gas or an ideal gas with very insignificant deviation from the perfect gas. Therefore all the perfect gas laws are equally applicable to air.

1. Boyle's Law

- ✓ *Boyle's law states that if temperature remains constant, the pressure of a confined mass of gas will vary inversely with its volume.*
- ✓ Mathematically, $P \propto \frac{1}{V}$ when $T = \text{constant}$ ... (10.4)

or $PV = \text{Constant}$

or $P_1V_1 = P_2V_2 = P_3V_3 = \ldots\ldots\ldots = P_nV_n$ ... (10.5)

[†] The term ***relative humidity*** can be defined as the ratio of the partial pressure of water vapour in a given volume of mixture to the partial pressure of water vapour when the same volume of mixture is saturated at the same temperature.

2. Charles' Law

- ✓ *Charles' law states that pressure remaining constant, the volume of a given mass of gas will vary directly as its absolute temperature.*
- ✓ Mathematically, $V \propto T$ when $P = \text{constant}$ ... (10.6)

or $\frac{V}{T} = \text{Constant}$

or $\frac{V_1}{T_1} = \frac{V_2}{T_2} = \frac{V_3}{T_3} = \ldots\ldots\ldots = \frac{V_n}{T_n}$ ... (10.7)

3. Gay-Lussac's Law

- ✓ *Gay-Lussac's law states that volume remaining constant, the pressure of a confined mass of gas will vary directly as its absolute temperature.*
- ✓ Mathematically, $P \propto T$ when $V = \text{constant}$ ... (10.8)

or $\frac{P}{T} = \text{Constant}$

or $\frac{P_1}{T_1} = \frac{P_2}{T_2} = \frac{P_3}{T_3} = \ldots\ldots\ldots = \frac{P_n}{T_n}$ ... (10.9)

4. General Gas Law

- ✓ Boyle's, Charles', and Gas-Lussac's laws can be combined to obtain the general gas law and is given by,

$\frac{PV}{T} = \text{Constant}$ ... (10.10)

or $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} = \frac{P_3V_3}{T_3} \ldots\ldots\ldots\ldots = \frac{P_nV_n}{T_n}$ ... (10.11)

Note In the perfect gas law, the P and T represents absolute pressure and absolute temperature (in °K) respectively.

10.3.4. Other Properties of Air

The properties, discussed in Section 2.3–2.12, such as density, specific volume, viscosity, compressibility, bulk modulus, *etc.*, are also equally applicable to the air.

10.4. BASIC PNEUMATIC SYSTEM

As discussed in Section 1.8, pneumatic systems have components that are similar to those used in hydraulic systems.

10.4.1. Components of a Pneumatic System

The basic components required for any pneumatic system are presented in Table 10.1.

Table 10.1. Components of a pneumatic system

1. ***Compressor :*** ✓ A compressor is a device used to compress the air that comes directly from the atmosphere.
   - ✓ The compressor, considered as an air source, supplies the required quantity of air.

2. ***Air tank (or Receiver tank) :*** The air tank stores a given volume of compressed air coming out from the compressor.

3. ***Prime mover :*** An electric motor or other prime mover is used to drive the compressor.

4. ***Fluid conditioners (or air processing equipment) :*** The purpose of fluid conditioners is to make the compressed air more acceptable medium for the pneumatic system.

   The important air processing equipment are as follows :

   - *(i)* ***Air filters :*** To remove contaminants from the air before it reaches pneumatic components such as valves and actuators.
   - *(ii)* ***Air pressure regulator :*** To reduce the air pressure to the desired level for the particular circuit application.
   - *(iii)* ***Air lubricator :*** To ensure proper lubrication of internal moving parts of pneumatic components.
   - *(iv)* ***Air dryers :*** To remove the moisture from the air leaving the compressor.
   - *(v)* ***Pneumatic silencer (or muffler) :*** To control the noise caused by a rapidly exhausting air stream flowing into the atmosphere.

5. ***Control valves :*** ✓ Control valves are used to control air direction, pressure, and flow rate.
   - ✓ The important control valves include check valve, shuttle valve, directional control valve, and flow control valve.

6. ***Pneumatic actuators :*** The actuator is used to convert the energy of the compressed air into mechanical force or torque to do useful work.
   - ✓ Actuators can be cylinders to provide linear motion, or motors to provide rotary motion.

7. ***Piping :*** The pneumatic piping carries the air from one location to another.

10.4.2. Construction and Operation

Fig.10.2 illustrates a typical pneumatic system which uses compressed air to obtain the useful mechanical work through the pneumatic actuator. This self-explanatory circuit consists of compressor, receiver tank, air processing equipment (filter, regulator, and lubricator), control valves (4 way manual DC valve and two adjustable flow control valves), pneumatic actuator, and miscellaneous components such as piping, pressure gauges, and water drain.

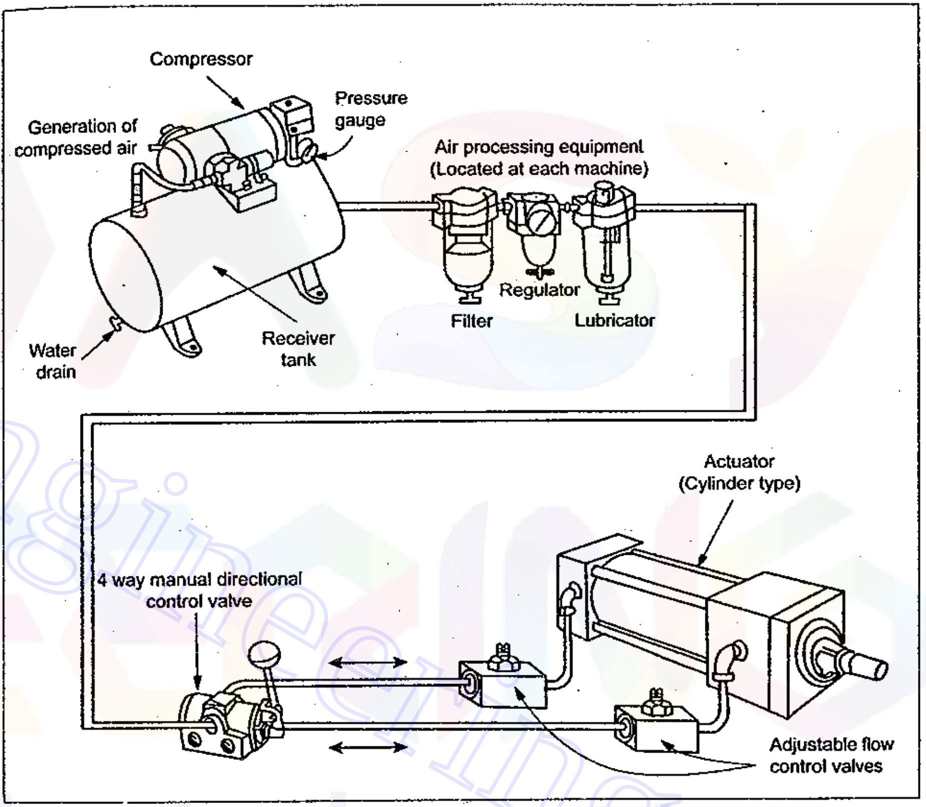

Compressor
Pressure gauge
Generation of compressed air
Air processing equipment (Located at each machine)
Regulator
Filter
Lubricator
Water drain
Receiver tank
Actuator (Cylinder type)
4 way manual directional control valve
Adjustable flow control valves

Fig. 10.2. Typical pneumatic system illustrating basic components

10.5. SOME NUMERICAL EXAMPLES ILLUSTRATING PERFECT GAS LAWS

Example 10.1 *A compressed air receiver has a volume of 0.6 m^3 at 4 bar gauge pressure. If the volume of the same receiver is increased to 1 m^3, determine the gauge pressure of the air assuming a constant temperature process.*

Given Data : $V_1 = 0.6 \text{ m}^3$; $P_1 \text{ (gauge)} = 4 \text{ bar}$; $V_2 = 1 \text{ m}^3$; $T = \text{Constant}$.

☺ ***Solution :*** Given that temperature remains constant, therefore applying Boyle's law, we get

$$P_1 V_1 = P_2 V_2$$

Here the P_1 and P_2 represents absolute pressures.

Given that, $P_{1\,(gauge)} = 4$ bar

$\therefore$ $P_{1\,(absolute)} = P_{1\,(gauge)} + P_{atm} = 4 + 1 = 5$ bar

Now, $5 \times 0.6 = P_2 \times 1$ or $P_{2\,(absolute)} = 3.0$ bar

$\therefore$ $P_{2\,(gauge)} = P_{2\,(absolute)} - P_{atm} = 3 - 1 = \mathbf{2\ bar}$ **Ans.** ☜

Example 10.2 *The 50 mm diameter piston of the pneumatic cylinder of Fig.10.3 retracts 150 mm from its present position ($P_1 = 2.5$ bars gauge, $V_1 = 350$ cm³) due to the external load on the rod. If the port at the blind end of the cylinders is blocked, find the new pressure, assuming the temperature does not change.*

Given Data : $D_{piston} = 50$ mm ; Stroke = L = 150 mm ; P_1 (gauge) = 2.5 bar;
$V_1 = 350\ \text{cm}^3 = 350 \times 10^{-6}\ \text{m}^3$; T = Constant.

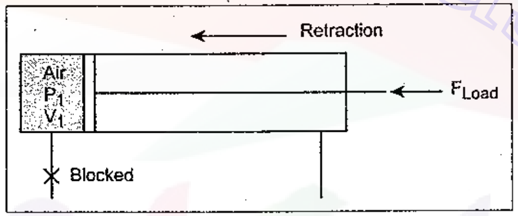


Fig. 10.3.

☺ ***Solution :*** $P_{1\,(absolute)} = P_{1\,(gauge)} + P_{atm} = 2.5 + 1 = 3.5$ bar

$$\text{Final volume, } V_2 = V_1 - \left(\frac{\pi}{4} D^2 L\right)$$

$$= (350 \times 10^{-6}) - \left[\frac{\pi}{4} (0.05)^2\, 0.15\right] = 5.547 \times 10^{-5}\ \text{m}^3$$

Now using the Boyle's law, we get

$$P_1 V_1 = P_2 V_2$$

or $3.5\,(350 \times 10^{-6}) = P_2\,(5.547 \times 10^{-5})$

or $P_{2\,(absolute)} = 22.08$ bar

$\therefore$ $P_{2\,(gauge)} = P_{2\,(absolute)} - P_{atm}$

$= 22.08 - 1 = \mathbf{21.08\ bar}$ **Ans.** ☜

Example 10.3 *The cylinder of Fig.10.3 has an initial position where $P_1 = 2.5$ bars gauge and $V_1 = 350$ cm³, as controlled by the load on the rod. The air temperature is 35°C. The load on the rod is held constant to maintain constant air pressure, but the air temperature is increased to 70°C. Find the new volume of air at the blind end of the cylinder.*

Given Data : $P_{1\,(gauge)} = 2.5$ bar; $V_1 = 350$ cm³ ; $T_1 = 35°\text{C} = 35 + 273 = 308$ K;
P = constant ; $T_2 = 70°\text{C} = 70 + 273 = 343$ K

☺ ***Solution :*** Given that pressure is constant, so using the Charles' law, we get

$$\frac{V}{T} = \text{constant} \quad \text{or} \quad \frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{350 \times 10^{-6}}{308} = \frac{V_2}{343} \qquad [\because \text{ The values of } T_1 \text{ and } T_2 \text{ should be expressed in K}]$$

or $V_2 = \mathbf{389.77 \times 10^{-6}\ m^3}$ or $\mathbf{389.77\ cm^3}$ **Ans.** ☜

Example 10.4 *The cylinder of Fig.10.3 has a locked position (V_1 = constant). P_1 = 2.5 bars gauge and $T_1 = 30$°C. If the temperature increases to 75°C, what is the new pressure in the blind end ?*

Given Data : V_1 = Constant ; $P_{1\,(gauge)} = 2.5$ bars or $P_{1\,(absolute)} = 2.5 + 1 = 3.5$ bars;
$T_1 = 30°\text{C} = 30 + 273 = 303$ K ; $T_2 = 75°\text{C} = 75 + 273 = 348$ K.

☺ ***Solution :*** Given that volume is constant, so applying the Gay-Lussac's law, we get

$$\frac{P}{T} = \text{Constant} \quad \text{or} \quad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

or $\dfrac{3.5}{303} = \dfrac{P_2}{348}$ or $P_{2\,(absolute)} = 4.02$ bars

or $P_{2\,(gauge)} = P_{2\,(absolute)} - P_{atm} = 4.02 - 1 = \mathbf{3.02\ bar}$ **Ans.** ☜

Example 10.5 *Gas at 75 bars gauge and 45°C is contained in the 1000 cm³ cylinder of Fig.10.4. A piston compresses the volume to 750 cm³ while the gas is heated to 110°C. What is the final pressure in the cylinder.*

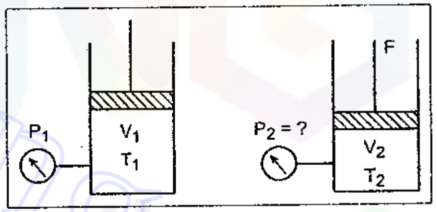


Fig. 10.4.

Given Data : $P_{1\,(gauge)} = 75$ bars or $P_{1\,(absolute)}$
$= 75 + 1 = 76$ bars;
$T_1 = 45°\text{C} = 45 + 273 = 318$ K;
$V_1 = 1000$ cm³ ; $V_2 = 750$ cm³ ;
$T_2 = 110°\text{C} = 110 + 273 = 383$ K.

☺ ***Solution :*** We know the general gas law that,

$$\frac{PV}{T} = \text{Constant} \quad \text{or} \quad \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{76\,(1000 \times 10^{-6})}{318} = \frac{P_2\,(750 \times 10^{-6})}{383}$$

or $$P_{2\,(\text{absolute})} = 122.05 \text{ bars}$$

or $$P_{2\,(\text{gauge})} = 122.05 - 1 = \mathbf{121.05 \text{ bars}}$$ **Ans.** ☜

REVIEW AND SUMMARY

- ✓ *In this chapter, the introductory concepts of the pneumatics have been presented.*
- ✓ *The **pneumatics** may be defined as that branch of engineering-science which deals with the study of the behaviour and application of compressed air.*
- ✓ ***Pneumatic systems** use pressurized gases as their medium to transmit and control power.*
- ✓ ***Air** is popularly used as the fluid medium in almost all pneumatic systems, because air is safe, low-cost, and readily available fluid.*
- ✓ *The advantages, disadvantages, applications, and selection of pneumatic systems have been described in this chapter.*
- ✓ *Air is a mixture of gases containing about 78% nitrogen, 21% oxygen, and 1% other gases such as argon and carbon dioxide.*
- ✓ *Absolute pressure = Gauge pressure + Atmospheric pressure.*
- ✓ *The atmospheric pressure decreases with the increase in altitude.*
- ✓ ***Standard air** is sea-level air having a temperature of 20°C, pressure of 1.013 bar, and a relative humidity of 36%.*
- ✓ ***Perfect gas laws :***
  1. ***Boyle's law :*** $PV = \text{Constant}$ or $P_1 V_1 = P_2 V_2$
  2. ***Charles' law :*** $\frac{V}{T} = \text{Constant}$ or $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
  3. ***Gay-Lussac's law :*** $\frac{P}{T} = \text{Constant}$ or $\frac{P_1}{T_1} = \frac{P_2}{T_2}$
  4. ***General gas law :*** $\frac{PV}{T} = \text{Constant}$ or $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
- ✓ *The **basic components** required for any pneumatic system are :*
  1. *Air compressor,*
  2. *Air tank,*
  3. *Prime mover,*
  4. *Air processing equipment*
     - *(i) Air filters,*
     - *(ii) Air pressure regulator,*
     - *(iii) Air lubricator,*
     - *(iv) Air dryer, and*
     - *(v) Pneumatic silencer.*
  5. *Control valves,*
  6. *Pneumatic actuators, and*
  7. *Piping.*

KEY TERMS ONE SHOULD REMEMBER

Pneumatics
Pneumatic systems
Air
Atmospheric pressure
Standard air

Gas laws
  Boyle's law
  Charles' law
  Gas-Lussac's law
  General gas law
Compressor
Air tank
Prime mover

Fluid conditioners
  Filter
  Regulator
  Lubricator
  Air dryer
  Silencer
Control valves
Actuators
Piping

REVIEW QUESTIONS

Short Answer Type Questions

1. Define 'pneumatics'.
2. Why is air used as the fluid medium in all pneumatic systems ?
3. 'Pneumatic systems cannot provide precise actuator control'—Why ?
4. 'Pneumatic systems cannot be applied to high-pressure applications'—Why ?
5. Name any four applications of pneumatic systems.
6. For what type of application, you would prefer to use pneumatic systems rather than hydraulic systems.
7. Give the composition of air.
8. What is meant by atmospheric pressure ? Give the relationship between atmospheric, absolute, and gauge pressures.
9. Show the graph explaining the pressure variation with altitude.
10. What do you mean by standard air ?
11. State the following perfect gas laws :
    (*i*) Boyle's law, (*ii*) Charles' law,
    (*iii*) Gay-Lussac's law, and (*iv*) General gas law.
12. Name any six basic components required in a pneumatic circuit.

Essay Answer Type Questions

1. (*a*) What are the reasons for considering the use of pneumatic systems instead of hydraulic systems ?
   (*b*) What are the major drawbacks of using pneumatic systems.
   (*c*) How can you select a fluid medium for a given application.
2. With a simple sketch, explain the functions and working of basic components required for a pneumatic system.

PROBLEMS FOR PRACTICE

1. The atmospheric air is compressed by an compressor to 1/5th the volume. What is the gauge pressure of compressed air, assuming the temperature does not change.

   [*Hint* : $\frac{V_2}{V_1} = \frac{1}{5}$ and $P_1 = 1$ bar are given; now use Boyle's law.] [*Ans.* 5 bar]

2. 500 cm³ of air at temperature 30°C, contained in a cylinder, is heated at constant pressure to a temperature of 70°C. Calculate the increase in volume of air ?

   [*Ans.* 66 cm³]

3. Air is contained in a cylinder at $P_1 = 3$ bar gauge, and $T_1 = 25°C$. If the air is heated to 80°C without changing its volume, what is the new pressure of the air ?

   [*Ans.* 3.74 bar gauge]

4. Gas at 50 bars gauge and 60°C is contained in the 0.75 m³ cylinder. The gas is compressed to the volume of 0.6 m³ and the temperature increases to 130°C. What is the final pressure of the gas ? [*Ans.* 76.15 bars gauge]

□□

Chapter 11

Air Compressors and Fluid Conditioners

"The important thing is not to stop questioning. Curiosity has its own reason for existing."
–Albert Einstein

"Character cannot be developed in ease and quiet. Only through experience of trial and suffering can the soul be strengthened, vision cleared, ambition inspired, and success achieved."
–Helen Keller

"It is a thousand times better to have common sense without education than to have education without common sense."
–Robert Green Ingersoll

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Understand and appreciate the use of air compressors in pneumatic systems.

☑ Describe the construction, operation, merits, and ranges of various type compressors including piston-, screw-, and vane-type compressors.

☑ Determine the size of compressor air receivers for an application.

☑ Understand and appreciate the purpose of various fluid conditions.

☑ Determine the air capacity ratings and the power required to drive compressors for an application.

☑ Describe the purpose, construction and operation of various fluid conditioners including air filters, air pressure regulators, air lubricators, mufflers, and air dryers.

Apprise Education, Reprise Innovations

CHAPTER 11

AIR COMPRESSORS AND FLUID CONDITIONERS

11.1. INTRODUCTION

As we know the vast majority of pneumatic systems use compressed atmospheric air as the working medium. The performance of the pneumatic system and its components mainly depend on the compressed air supply. The compressor compresses the atmospheric air into the compressed air and supplies the necessary quantity of air with required pressure. Before the compressed air is being supplied to other circuit components, it should be conditioned/processed so as to achieve better and safe operations. For this purpose, fluid conditioners such as filters, regulators, lubricators, mufflers, and air dryers are used.

In this chapter, we shall describe the purpose, construction, and operation of various compressors and fluid conditioners.

COMPRESSORS

11.2. COMPRESSORS

11.2.1. What is a Compressor ?

- ✓ A compressor is a device used to compress air (or any gas) from a low inlet pressure (usually atmospheric pressure) to a higher desired pressure level.
- ✓ In pneumatic systems, compressors are used to compress and supply the required quantities of air.
- ✓ As per the laws of perfect gas, the compressor increases the pressure of the air by reducing its volume.

11.2.2. Types of Air Compressors

- ✓ There are two basic types of compressors, based on their method of energy transfer and pressure generation. They are :
    1. Positive displacement compressors, and
    2. Dynamic type compressors.
- ✓ ***Positive displacement compressors*** work on the principle of increasing the pressure of a definite volume of air by reducing that volume in an enclosed chamber.
- ✓ ***Dynamic compressors,*** also known as ***turbo compressors,*** employs rotating vanes or impellers to increase the pressure of the air.

✓ The detailed sub-classification of compressors are presented in Fig.11.1.

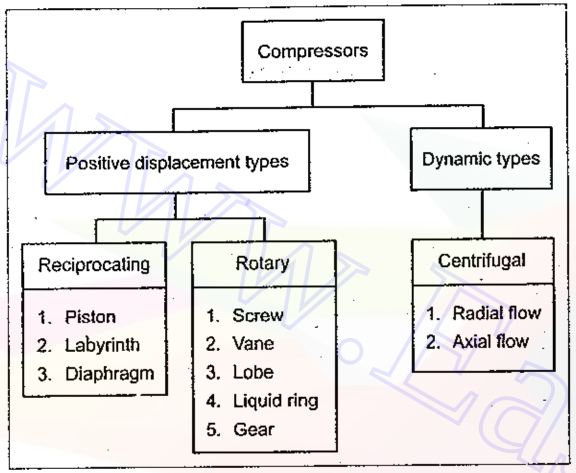


Fig. 11.1. Types of air compressors

However, the study of piston-, screw-, and vane-type compressors are more important from our subject point of view.

11.3. PISTON-TYPE RECIPROCATING COMPRESSOR

✓ Piston compressors are the most commonly used compressors in the fluid power industry.

✓ The construction and working of a piston-type reciprocating compressor is very much similar to that of an internal combustion (IC) engine.

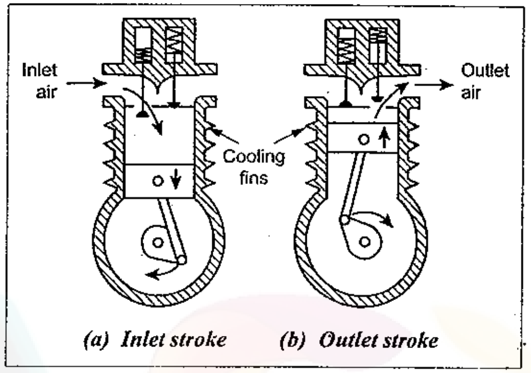
11.3.1. Construction

A typical piston-type reciprocating compressor consists of a cylinder, cylinder head, piston with piston rings, inlet and outlet valves, connecting rod, crank, crankshaft, bearings, *etc*. The arrangement of a basic single cylinder compressor is illustrated in Fig.11.2.

11.3.2. Operation

First a prime mover, mostly an electric motor, is used to drive the compressor unit. The electric motor supplies the rotary motion to the crank shaft, which in turn converted into reciprocating motion of piston through the crank and connecting rod arrangement.

Inlet stroke : During the downward motion of he piston [Fig.11.2(*a*)], the pressure inside the cylinder falls below the atmospheric pressure and the inlet valve is opened due to the pressure difference. The air is drawn into the cylinder until the piston reaches the bottom of the stroke.



(a) Inlet stroke ***(b) Outlet stroke***

Fig. 11.2. Single cylinder compressor

Outlet stroke : As the piston starts moving upwards [Fig.11.2(*b*)], the inlet valve is closed and the pressure starts increasing continuously until the pressure inside the cylinder is above the pressure of the delivery side which is connected to the receiver. Then the outlet valve opens and air is delivered during the remaining upward motion of the piston to the receiver.

11.3.3. Multicylinder Piston Compressors

Though a single-cylinder compressor can provide pressure upto about 10 bars, usually a multicylinder compressors (having 2 to 16 cylinders) are used for increasing compression capacity and also due to many practical reasons.

11.3.4. Single Stage and Multi-Stage Compressors

✓ In ***single stage compressor,*** the compression of the air from the initial pressure to the final pressure is carried out in one cylinder only.

✓ When the compression of air from the initial pressure to the final pressure is carried out in more than one cylinder, then the compressor is known as ***multi-stage compressor.***

✓ ***Staging :*** Staging means dividing the total pressure among two or more cylinders by allowing the outlet from one cylinder into the inlet of the next cylinder and so on.

✓ ***Why should we go for staging ?***

As we know, as per the general gas laws, the compression of air will result in significant increase in temperature. For instance, if a single-stage compressor gives the compressed air of about 5 bar, the compressed air temperature can rise to over 200°C. This in turn increase the motor power needed to drive the compressor. Thus the effective cooling of compressor is necessary.

When the multistage compressors are used, the effective cooling can be implemented between stages. This effective cooling (*i*) reduces input power requirements, and (*ii*) increases the efficiency of the compressor.

✓ A typical, self-explanatory, two-stage compressor arrangement is illustrated in Fig.11.3.

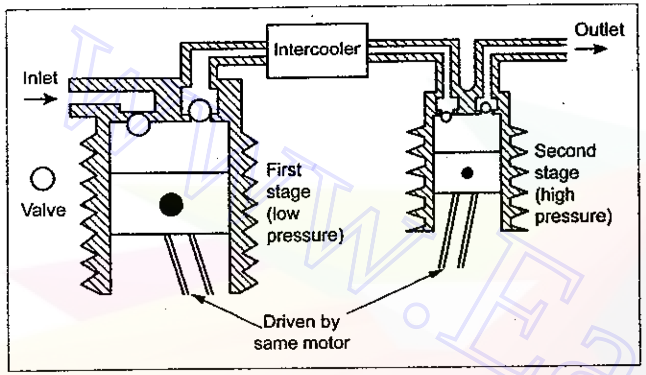


Fig. 11.3. Two-stage compressor

✓ To get the practical feel of a compressor unit, the simple view of a reciprocating air-compressor unit showing various external parts is presented in Fig.11.4.

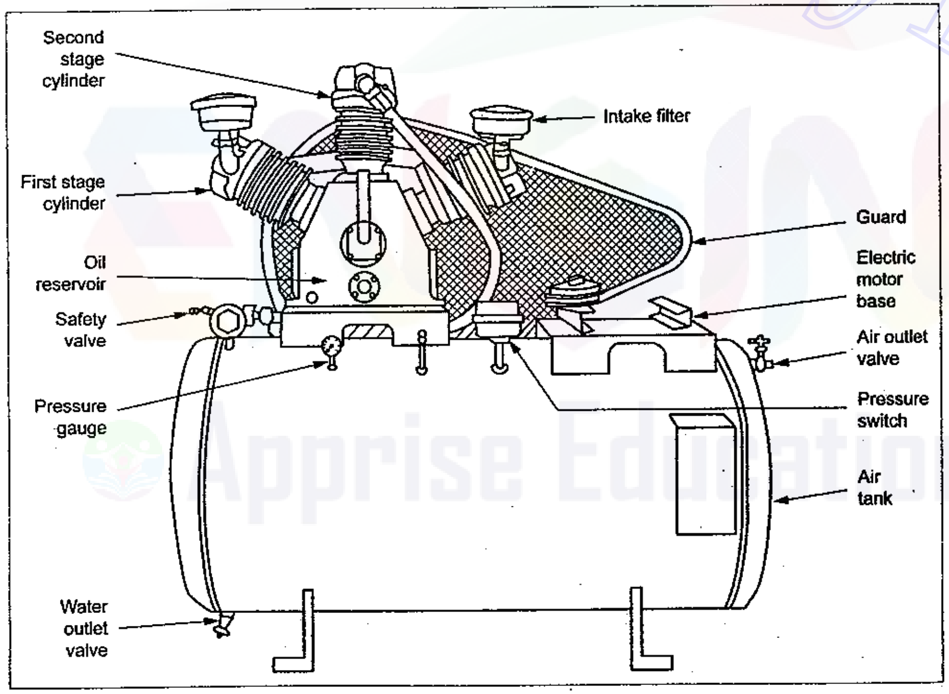


Fig. 11.4. Parts of reciprocating air compressor

11.3.5. Advantages

1. Piston type compressors are available in wide range of capacity and pressure.
2. The overall efficiency of piston compressors are high when compared to other compressors.
3. Very high air pressure and air volume flow rate can be obtained by using the multistage compressors.
4. Better mechanical balance can be achieved with multi-stage compressors.

11.3.6. Ranges

The single-stage screw compressors are available with capacities upto 1250 m^3/hr and pressures of 10 bars. The multi-stage screw compressors are available with pressure upto about 350 bar.

11.3.7. Need for Compressor Starting Unloader Control

✓ Once a pressure has been developed in the compressed air piping, the established air pressure will push back against the compressor. This makes starting the compressor more difficult when required. So an arrangement called 'starting unloader control' is required to start the compressor whenever desired. This arrangement releases the pressure in the piping to the atmosphere and now the compressor is free to start whenever needed.

✓ When the air compressor is started for the very first time, the starting unloader control is not required as there is no established pressure against which the compressor must start.

11.4. SCREW COMPRESSORS

Screw compressors are used in many applications where medium pressures (< 10 bar) and medium volumes of air (upto 5000 m^3/hr) are required.

11.4.1. Construction

The construction and operation of a screw compressor is very similar to a hydraulic screw pump described in Section 5.10. A typical screw lobe compressor having unsymmetrical profile of screw rotors is illustrated in Fig.11.5.

As shown in Fig.11.5, it consists of two screws—one with convex and the other with concave contour, generally called male and female rotor respectively. Also a minimal clearance is maintained between the two intermeshing rotating screws.

11.4.2. Operation

As the screws rotate, air is sucked into the housing through the inlet port. The sucked air is trapped between the screws and carried along to the outlet port.

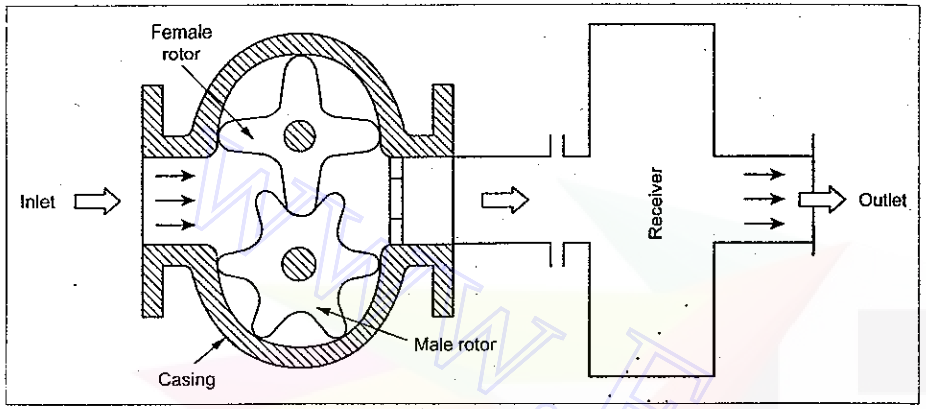


Fig. 11.5. Screw compressor

11.4.3. Advantages

The advantages of screw compressors are :

1. Simplicity.
2. Fewer moving parts rotating at a constant speed.
3. Steady delivery of air without pressure pulses.

11.4.4. Ranges

The single-stage screw compressors are available with capacities upto 2500 m^3/hr and pressures of 8 bars.

11.5. ROTARY VANE COMPRESSOR

The rotary vane type compressors are used in applications where low-pressure and low-volume are needed. For example, they are used for instrument and other laboratory-type air needs.

11.5.1. Construction

The construction and operation of a rotary vane compressor is very much similar to a hydraulic vane pump described in Section 5.11. A typical sliding-vane-type rotary compressor is illustrated in Fig.11.6.

It consists of a rotor located eccentrically in a cylindrical outer casing. The rotor carries a set of spring-loaded vanes in the slots of the rotor, as shown in Fig.11.6.

11.5.2. Operation

The air at atmospheric pressure is entrapped between two vanes. As the rotor rotates, the entrapped air is compressed between the vanes and then discharged through a port to the receiver.

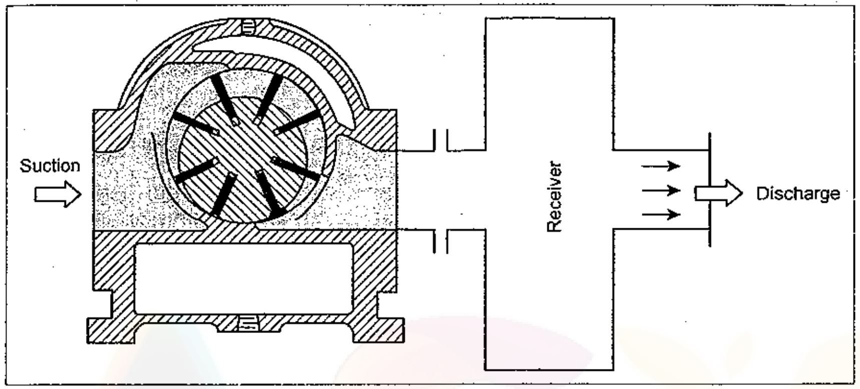
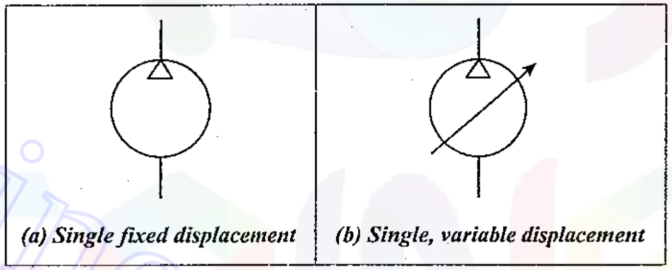


Fig. 11.6. Rotary vane compressor

11.5.3. Graphic Symbol

The symbolic representation of compressors are shown in Fig.11.7.



(a) Single fixed displacement *(b) Single, variable displacement*

Fig. 11.7. Compressor graphic symbols

11.5.4. Advantages

1. Rotary vane compressors are pulse free and therefore can be used without a receiver if needed.
2. They are smaller in size and lighter in weight.
3. They can work at high speed.

11.5.5. Ranges

The rotary vane type compressors are available with capacities upto 3000 m^3/hr and pressures of 3 to 10 bars.

11.5.6. Specification of Compressors

Air compressors are generally specified/rated by the following :

1. Outlet pressure of air that can be delivered by the compressor,
2. Capacity or volume of air that can be delivered by the compressor, and
3. Compressor configuration and cylinder geometry.

11.5.7. Analysis of Air Capacity Rating of Compressors

Q_1 and Q_2 = Volume flow rate of air at the compressor inlet and outlet respectively (m³/min),

P_1 and P_2 = Absolute pressure of air at the compressor inlet and outlet respectively (kPa abs),

and T_1 and T_2 = Absolute temperature of air at the compressor inlet and outlet respectively (°K).

Then,

$$Q_1 = Q_2 \left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right) \qquad \ldots (11.1)$$

11.5.8. Analysis of Sizing of Air Receivers

The air receiver size can be determined by using the following equation :

$$V_r = \frac{101\, t\, (Q_r - Q_c)}{P_{max} - P_{min}} \qquad \ldots (11.2)$$

where V_r = Receiver size (m³),

t = Time that receiver can supply required amount of air (min),

Q_r = Consumption rate of pneumatic system (standard m³/min)[†],

Q_c = Output flow rate of compressor (standard m³/min),

P_{max} = Maximum pressure level in receiver (kPa), and

P_{min} = Minimum pressure level in receiver (kPa).

11.5.9. Analysis of Power Required to Drive Compressors

The theoretical power required to drive an air compressor can be determined by using the following equations :

(*i*) Theoretical power (kW)

$$= \frac{P_{in}\, Q}{17.1}\left[\left(\frac{P_{out}}{P_{in}}\right)^{0.286} - 1\right] \qquad \ldots (11.3)$$

where P_{in} = Inlet atmospheric pressure (kPa abs),

P_{out} = Outlet pressure (kPa abs), and

Q = Flow rate (standard m³/min).

(*ii*) Actual power (kW)

$$= \left\{\begin{matrix}\text{Overall compressor} \\ \text{efficiency } (\eta_o)\end{matrix}\right\} \times \left\{\begin{matrix}\text{Theoretical} \\ \text{power}\end{matrix}\right\} \qquad \ldots (11.4)$$

[†] Standard m³/min means the inlet air volume (in m³/min) is at the standard atmospheric conditions of 1.013 bar and 20°C.

Example 11.1 ***Air is used at a rate of 1.25 m³/min from a receiver at 45°C and 12 bar gauge. How many standard m³/min of free air must the compressor provide ?***

Given Data : $Q_2 = 1.25$ m³/min; $T_2 = 45°C = 45 + 273 = 318$ K;

$P_{2\,(gauge)} = 12$ bar or $P_{2\,(absolute)} = 12 + 1 = 13$ bar $= 1300$ kPa

☺ ***Solution :*** It is given that standard free air is used as the inlet. So the standard

$P_{1\,(absolute)} = 1$ bar $= 100$ kPa and $T_1 = 20°C = 20 + 273 = 293°C$

We know that,

$$Q_1 = Q_2\left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right) = 1.25\left(\frac{1200}{100}\right)\left(\frac{293}{318}\right)$$

$$= \mathbf{13.82\ m^3/min\ of\ free\ air}$$ **Ans.** ☜

That means, the compressor must receive atmospheric air (1 bar and 20°C) at a rate of 13.82 m³/min in order to deliver air (12 bar and 45°C) at 1.25 m³/min.

Example 11.2 ***(i) Calculate the required size of a receiver that must supply air to a pneumatic system consuming 0.85 standard m³/min for 8 min between 10 bar and 7 bar before the compressor resumes operation.***

(ii) What size is required if the compressor is running and delivering air at 0.2 standard m³/min ?

Given Data : $Q_r = 0.85$ m³/min ; $t = 8$ min ; $P_{max} = 10$ bar $= 1000$ kPa ;

$P_{min} = 7$ bar $= 700$ kPa.

☺ ***Solution : (i) Required receiver size before the compressor starts operation :***

Since compressor has not started its operation, the output flow rate of compressor, $Q_C = 0$.

Receiver size,

$$V_r = \frac{101\, t\, (Q_r - Q_c)}{P_{max} - P_{min}} = \frac{101 \times 8 \times (0.85 - 0)}{1000 - 700} = \mathbf{2.289\ m^3}$$ **Ans.** ☜

(ii) Required receiver size when the compressor is running and delivering air at 0.2 standard m³/min :

Given that $Q_c = 0.2$ m³/min

∴ Receiver size,

$$V_r = \frac{101 \times 8 \times (0.85 - 0.2)}{1000 - 700} = \mathbf{1.75\ m^3}$$ **Ans.** ☜

Example 11.3 ***Determine the actual power required to drive a compressor that delivers air at 3.5 standard m³/min at 8 bar gauge. The overall efficiency of the compressor is 74%.***

Given Data : $Q = 3.5$ m³/min ; $P_{out\,(gauge)} = 8$ bar or $P_{out\,(abs)} = 8 + 1 = 9$ bar $= 900$ kPa; $\eta_0 = 74\%$.

☺ ***Solution :*** Since standard atmospheric air is the inlet air, $P_{in\,(abs)} = 1$ bar $= 100$ kPa.

$$\text{Theoretical power (kW)} = \frac{P_{in}\,Q}{17.1}\left[\left(\frac{P_{out}}{P_{in}}\right)^{0.286} - 1\right]$$

$$= \frac{100 \times 3.5}{17.1}\left[\left(\frac{900}{100}\right)^{0.286} - 1\right] = \mathbf{17.9\ kW}\quad \textbf{Ans.}$$

$$\therefore \text{The actual power (kW)} = \text{Theoretical power (kW)} \times \eta_0$$

$$= 17.9 \times 0.74 = \mathbf{13.25\ kW}\quad \textbf{Ans.}$$

FLUID CONDITIONERS

11.6. FLUID CONDITIONERS

11.6.1. Introduction

The atmospheric air that is compressed in the compressor is obviously not clean because the atmospheric air contains many contaminants such as smoke, dirt, water vapour, *etc.* This contaminated air may lead to excessive wear and failure of pneumatic components. The system performance and accuracy depend mainly on the supply of clean, dry and contamination-free compressed air. Therefore fluid conditioners are used to condition the compressed air before leaving into various pneumatic components.

11.6.2. What are Fluid Conditioners ?

✓ ***Purpose :*** The purpose of fluid conditions is to make the compressed air more acceptable and suitable fluid medium for the pneumatic system components as well as for operating personnel.

✓ ***Elements of fluid conditioners***

The important fluid conditioners are :

1. Filters,
2. Regulators,
3. Lubricators,
4. Mufflers, and
5. Air dryers.

In these, the first three units together are called FRL (Filter-Regulator-Lubricator) unit or service unit.

11.7. AIR FILTERS

11.7.1. What are Air Filters ?

✓ ***Functions :*** The function of air filters is to remove all foreign matter and allow dry, clean air to flow without restriction to the regulator and then on to the lubricator.

✓ Filters are available in wide ranges starting from a fine mesh wire cloth (which only strains out heavier foreign particles) to elements made of synthetic materials (which are designed to remove very small particles).

✓ Usually in-line filter elements can remove contaminants in the 5 to 50 μm range.

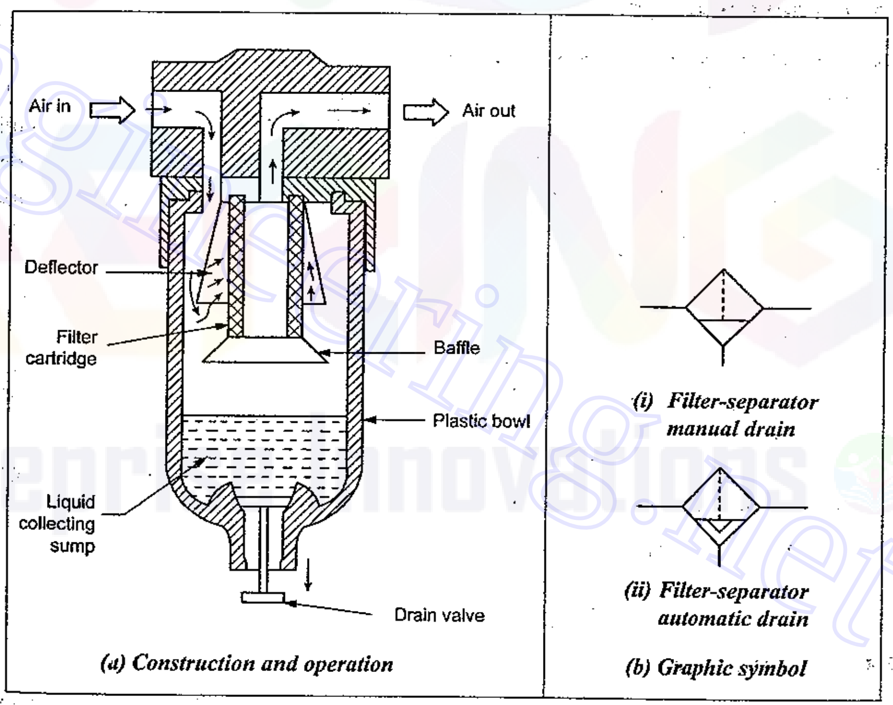
11.7.2. Factors Affecting Selection of Filters

While selecting the filters, the following factors at least should be taken into account :

1. Size of particles to be filtered from the system.
2. Capacity of the filter.
3. Accessibility and maintenability.
4. Life of the Filter.
5. Ability to drain the condensate.

11.7.3. Construction

The construction and operation of a typical cartridge-type filter system is illustrated in Fig.11.8(*a*).



(a) Construction and operation

(i) Filter-separator manual drain

(ii) Filter-separator automatic drain

(b) Graphic symbol

Fig. 11.8. Typical air-filter system

It consists of the filter cartridge, deflector, plastic bowl, baffle, water drain valve, *etc.*

11.7.4. Operation

The air to be filtered is allowed downward with a swirling motion that forces the moisture and the heavier particles to fall down. The deflector used in the filter mechanically separates the contaminants before they pass through the cartridge filter. The filter cartridge provide a random zig-zag passage for the air flow. This type of air flow arrests the solid particles in the cartridge passage.

The water vapour gets condensed inside the filter and is collected at the bottom of the filter bowl. Also heavier foreign particles that are separated from the air are collected at the bottom of the bowl. Then the accumulated water and other solid particles at the bottom of the filter bowl are drained off with the use of an on-off drain valve located at the bottom of the filter bowl.

11.7.5. Graphic Symbol

Fig.11.8(*b*) shows the graphic symbol for an air-filter.

11.8. AIR PRESSURE REGULATOR

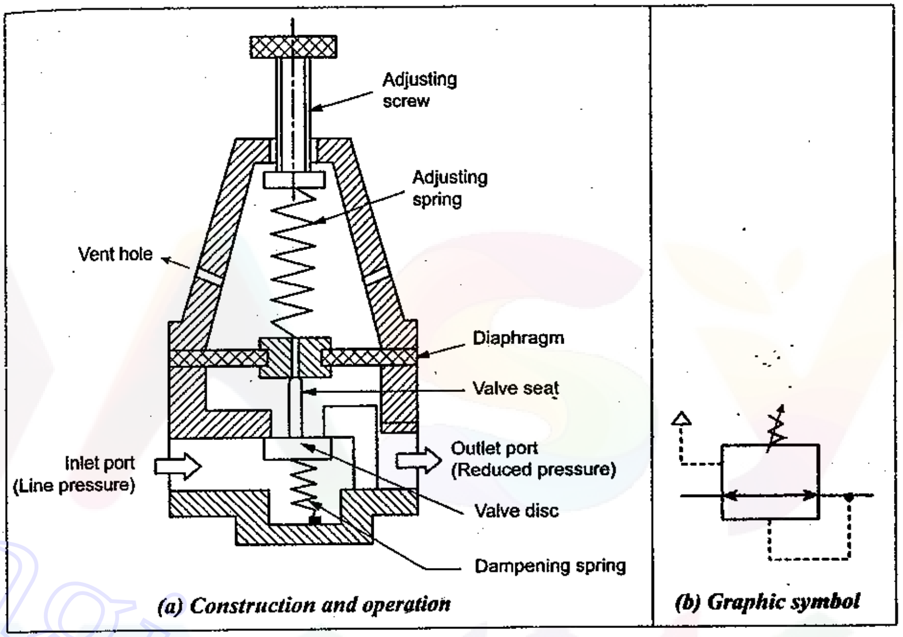
11.8.1. What are Air Pressure Regulators ?

- ✓ ***Function :*** The function of the air pressure regulator is to regulate the pressure of the incoming compressed air so as to achieve the desired air pressure at a steady condition.
- ✓ The compressed air leaving the compressor should be properly prepared before it goes into the circuit. The air should have the proper operating pressure for the circuit. Improper fluctuating pressure level in the piping system can adversely affect the operating characteristics of the system components such as valves, cylinders, *etc.* Therefore, air pressure regulators are fitted to ensure the constant supply pressure irrespective of the pressure fluctuations in the compressor unit.
- ✓ For example, the line from the compressor may carry a pressure of 10 bar, the air pressure regulator can reduce this pressure to 0 bar to any point between the full line pressure and zero pressure.
- ✓ Thus the air pressure regulators act as pressure guards by preventing pressure surges or drops from entering the air circuits.
- ✓ ***Types :*** The two types of air pressure regulators are :
  1. Diaphragm-type regulator, and
  2. Piston-type regulator.

11.8.2. Construction

The construction and operation of a typical diaphragm-type air pressure regulator is illustrated in Fig.11.9(*a*).

It consists of diaphragm, valve, main and dampening springs, *etc.* Usually the diaphragm is made of oil-resistant synthetic rubber with a nylon cloth reinforcements.



(a) Construction and operation *(b) Graphic symbol*

Fig. 11.9. Typical air pressure regulator

11.8.3. Operation

The diaphragm allows the proper amount of movement for opening and closing at the valve seat. When the adjusting screw is in the fully retracted position, the valve is closed. When the adjusting screw is turned to compress the adjusting and dampening springs, the valve is opened. Thus the air is allowed from inlet port to the outlet port.

The pressure of the outlet air depends upon the size of the valve opening that is maintained. This is determined by the compression of the adjustable spring. Higher the spring compression, more will be the amount of opening and hence more the pressure and vice versa.

The vent-holes are provided to let out the undesirable excessive outlet pressure, if any, into the atmosphere. The dampening spring is provided to act as a dampening device needed to stabilize the pressure.

11.8.4. Graphic Symbol

Fig.11.9(*b*) shows the graphic symbol of the air pressure regulator.

11.9. AIR LUBRICATOR

11.9.1. What is an Air Lubricator ?

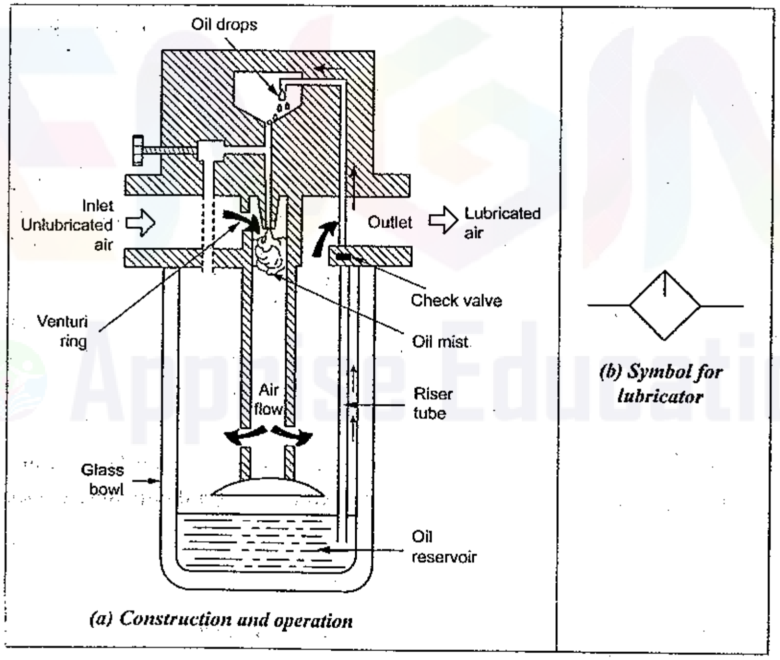
- ✓ *Function :* The function of an air lubricator is to add a controlled amount of oil with air to ensure proper lubrication of internal moving parts of pneumatic components.
- ✓ The lubricator adds the lubrication oil in the form of a fine mist to reduce the friction and wear of the moving parts of pneumatic components such as valves, packings used in air cylinders, *etc.*
- ✓ At the same time excessive lubrication is also undesirable. Excessive lubrication may result (*i*) malfunction components, (*ii*) increased environmental problems, and (*iii*) seizing of components after prolonged downtime.

11.9.2. What is the best type of Lubricant for a Pneumatic System ?

1. Generally a good-quality, light-grade spindle oil is used in pneumatic systems.
2. Sometimes, a mixture of 50% kerosene and 50% SAE 30 oil is also used as lubricant.

11.9.3. Construction and Operation

The construction and operation of a typical force-feed type air lubricator is illustrated in Fig.11.10(*a*). Its operation is similar to the principle of simple carburetor used in the petrol engines to obtain air-fuel mixture.



(a) Construction and operation

(b) Symbol for lubricator

Fig. 11.10. Air lubricator

As the air to be lubricated enters into the inlet pipe, the venturi ring located in the pipe increases its velocity of low. It causes a local reduction in the upper chamber. This pressure differential between upper and lower chambers causes suction of lubrication oil from the oil reservoir to the upper chamber. Now the oil in the form of mist is sprayed in the air stream and the air-oil mixture is obtained. This air-oil mixture is forced to swirl as it leaves the central cylinder causing more oil particles to be spread out of the air stream. The amount of oil dropping into the upper chamber can be controlled by a needle valve.

11.9.4. Graphic Symbol

Fig.11.10(*b*) shows the graphic symbol for an air lubricator.

11.9.5. FRL Unit

- ✓ In most pneumatic systems, the compressed air is first filtered and then regulated to the specific pressure and made to pass through a lubricator for lubricating the oil. Thus usually a filter, regulator, and lubricator are placed in the inlet line to each air circuit. These may be installed as separate units, but more often they are used in the form of a combined unit.
- ✓ The combination of filter, regular, and lubricator is often labelled as ***FRL unit*** or ***service unit.***
- ✓ Fig.11.11 illustrates the arrangement of a FRL unit.

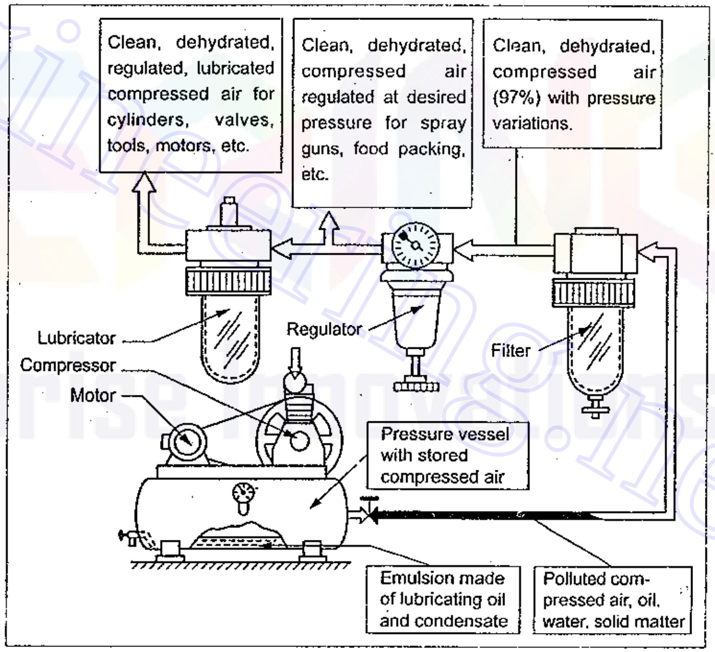
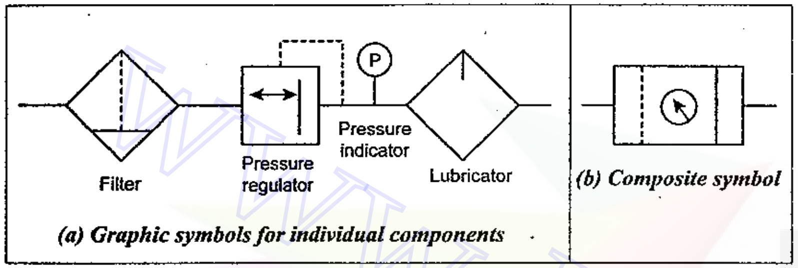

Clean, dehydrated, regulated, lubricated compressed air for cylinders, valves, tools, motors, etc.
Clean, dehydrated, compressed air regulated at desired pressure for spray guns, food packing, etc.
Clean, dehydrated, compressed air (97%) with pressure variations.
Lubricator
Compressor
Motor
Regulator
Filter
Pressure vessel with stored compressed air
Emulsion made of lubricating oil and condensate
Polluted compressed air, oil, water, solid matter

Fig. 11.11. Compressed air generation and distribution system showing a FRL unit

- ✓ ***Composite symbol :*** Fig.11.12 illustrates how individual component symbols form a composite symbol of a FRL unit.



(a) Graphic symbols for individual components

(b) Composite symbol

Fig. 11.12. FRL unit graphic symbol

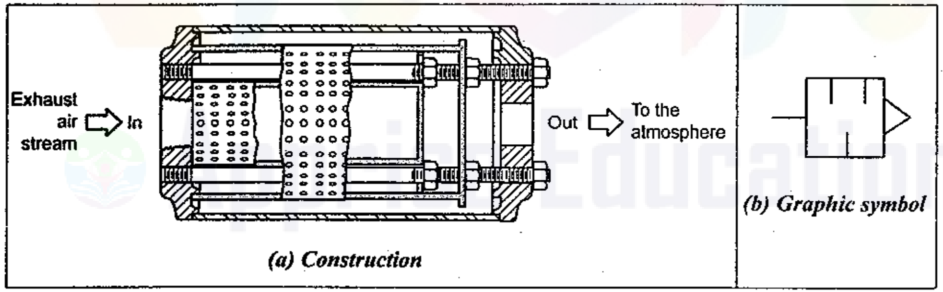
11.10. MUFFLERS (OR PNEUMATIC SILENCERS)

11.10.1. What are Mufflers ?

- ✓ ***Function :*** The function of muffler (also known as pneumatic exhaust silencer) is to control the noise caused by a rapidly exhausting air-stream flowing into the atmosphere.
- ✓ Noise created by air exhausting from an air system not only cause nervous tension and dissatisfaction among the operators, but also results in mental fatigue, lack of concentration, and inefficiency. This exhaust noises can be greatly reduced by installing a muffler at each pneumatic exhaust port.

11.10.2. Construction and Operation

The construction and operation of a typical pneumatic silencer is illustrated in Fig.11.13(*a*).



(a) Construction

(b) Graphic symbol

Fig. 11.13. Muffler

As shown in Fig.11.13 (*a*), the exhaust air stream enters one end, and passes out the another end after passing through a series of baffles. The baffle tubes are perforated with a large number of small holes. The outer shell acts as a barrier and helps guide the stream toward the exit to the atmosphere.

11.10.3. Graphic Symbol

Fig.11.13(*b*) shows the graphic symbol for a muffler.

11.11. AIR DRYERS

11.11.1. What are Air Dryers ?

- ✓ ***Function :*** The function of air dryers is to remove all water vapour/moisture from the air leaving the compressor.
- ✓ As we know, the atmospheric air contains moisture to a varying amount depending on the prevailing atmospheric conditions. Even after compression in the compressor, the air contains the same amount of moisture. This moisture should be removed before the air is fed into any pneumatic system components. Thus air dryers are placed at suitable points in the pressure air line to safeguard the pneumatic components from the corrosive effects of moisture.

11.11.2. Types of Air Dryers

- ✓ The three main types of air dryers used to remove the moisture in the compressed air are :

1. Refrigerated dryer,
2. Deliquescent dryer, and
3. Absorption dryer.

11.11.3. Construction and Operation

The construction and operation of a typical deliquescent-type dryer is illustrated in Fig.11.14.

It uses a chemical agent called a dessicant. As shown in Fig.11.14, the moisture air enters at one end, passes through the chemical agent, and passes out at the other end. The chemical agent absorbs water vapour/moisture and slowly dissolves it as a liquid. The liquid is collected at the bottom of the unit where it can be drained.

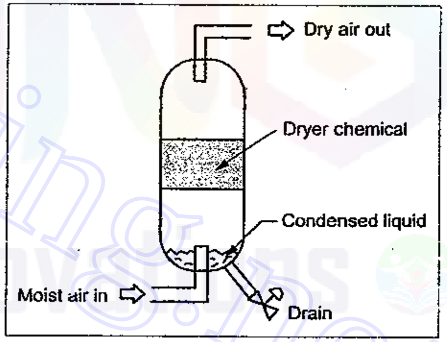


Fig. 11.14. Deliquescent dryer

REVIEW AND SUMMARY

✓ *A compressor is a device used to compress air from a low inlet pressure to a higher desired pressure level.*

✓ ***Types of air compressors :***

1. *Positive displacement compressors, and*
2. *Dynamic compressors.*

✓ *The construction, operation, advantages, disadvantages, and ranges of piston-, screw-; and vane-type compressors have been described in this chapter.*

✓ ***Formulae summary :***

1. Air capacity ratings of compressors : $Q_1 = Q_2 \left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right)$

2. Air receiver size : $V_r\,(m^3) = \dfrac{101\ t\,(min) \times (Q_r - Q_c)\ \text{std}\ m^3/min}{(P_{max} - P_{min})\ kPa}$

3. Power required to drive a compressor :

$$\text{Theoretical power (kW)} = \frac{P_{in}\,Q}{17.1}\left[\left(\frac{P_{out}}{P_{in}}\right)^{0.286} - 1\right]$$

and $$\text{Overall compressor efficiency (\%)} = \frac{\text{Actual power}}{\text{Theoretical power}} \times 100$$

✓ *The purpose of* ***fluid conditioners*** *is to make the compressed air more acceptable and suitable fluid medium for the pneumatic system components as well as for operating personnel.*

✓ *The various fluid conditioners includes :*

1. *Filters,*
2. *Regulators,*
3. *Lubricators,*
4. *Mufflers, and*
5. *Air dryers.*

✓ ***The function of air filters*** *is to remove all foreign matter and allow dry, clean air to flow without restriction to the regulator and then on to the lubricator.*

✓ ***The function of the air pressure regulator*** *is to regulate the pressure of the incoming compressed air so as to achieve the desired air pressure at a steady condition.*

✓ ***The function of an air lubricator*** *is to add a controlled amount of oil with air to ensure proper lubrication of internal moving parts of pneumatic components.*

✓ ***The function of a muffler*** *is to control the noise caused by a rapidly exhausting air stream flowing into the atmosphere.*

✓ ***The function of air dryers*** *is to remove all water vapour/moisture from the air leaving the compressor.*

✓ *The purpose, types, graphic symbol, construction, and operation of the above-said fluid conditioners are also presented in this chapter.*

KEY TERMS ONE SHOULD REMEMBER

Compressors
Positive displacement compressors
  Piston-type
  Screw-type
  Rotary-vane type
Staging
  Single stage compressors
  Multi-stage compressors
Air capacity rating of compressors
Air receiver size
Fluid conditioners
  Air filters
  Air pressure regulators
  Air lubricator
  Muffler
  Air dryers
FRL unit
Pneumatic silencer

REVIEW QUESTIONS

Short Answer Type Questions

1. What is the use of a compressor in a pneumatic system ?
2. List any four types of air compressors.
3. What does staging mean ?
4. What do you mean multi-stage compressors ? Why are they preferred over single-stage compressors ?
5. What is the purpose of compressor starting unloader control ?
6. How can you specify an air compressor ?
7. What is the purpose of fluid conditioners ?
8. Name any four fluid conditioners used in pneumatic systems.
9. What is the function of air filters ?
10. What are the factors affecting the selection of air filters ?
11. What is the purpose of an air pressure regulator ?
12. What is the use of lubricators applied in pneumatic systems ?
13. What kind of oil should be supplied to the lubricator ?
14. What do you mean by FRL unit ?
15. Why are mufflers used in pneumatic systems ?
16. What is the need for air dryers ?
17. Name various air dryers used to remove moisture from air ?
18. Draw graphic symbols for the following :
    (*i*) Air compressor, (*ii*) Filter,
    (*iii*) Regulator, (*iv*) Lubricator,
    (*v*) FRL unit, and (*vi*) Muffler.

Essay Answer Type Questions

1. (*a*) With a neat sketch, explain the construction and operation of a piston-type reciprocating compressor. Also bring out the advantages of employing it.
   (*b*) Write a brief about compressor starting unloader control.
2. Compare and contrast the construction, operation, advantages, and ranges of a screw-type compressor with a rotary vane-type compressor.
3. (*a*) Why is it necessary to keep compressed air clean, lubricated, and free from moisture ?
   (*b*) With a suitable sketch, describe the construction and operation of a cartridge-type air filter.
4. Explain the construction and operation of an air pressure regulator.
5. (*a*) With a simple sketch, explain how the compressed air can be lubricated.
   (*b*) Describe the operation of an 'FRL' trio unit.
6. (*a*) What is the importance of the pneumatic silencer ? With a sketch, discuss the operation and construction of a muffler.
   (*b*) With a neat sketch, explain the purpose, construction, and operation of an air dryer.

PROBLEMS FOR PRACTICE

1. Air is used at a rate of 1 m^3/min from a receiver 50°C and 10 bar gauge. If the atmospheric air is 1 bar and the atmospheric temperature is 20°C, how many standard m^3/min of free air must the compressor provide ? [*Ans.* 9.071 m^3/min]
2. (*i*) Calculate the required size of a receiver that must supply air to a pneumatic system consuming 1.2 standard m^3/min for 10 min between 12 bar and 8 bar before the compressor resumes operation.
   (*ii*) What size is required if the compressor is running and delivering air at 0.35 standard m^3/min ? [*Ans.* (*i*) 3.03 m^3 ; (*ii*) 2.14 m^3]
3. Determine the output pressure of a compressor operating with the following data :

Overall efficiency of compressor = 74%
Actual power required to drive the compressor = 15 kW
Compressor inlet pressure = Atmospheric
Compressor outlet flow rate = 4.25 standard m^3/min.

[*Hints* : 1. Find the theoretical power $= \dfrac{\text{Actual power}}{\text{Overall compressor efficiency}}$.
2. Using equation 11.3, find the unknown outlet pressure (P_{out})].

[*Ans.* 804.6 kPa absolute or 704.6 kPa gauge]

Chapter 12

Pneumatic Valves and Actuators

"The ultimate measure of a man is not where he stands in moments of comfort and convenience, but where he stands at times of challenge and controversy."
–Martin Luthur King, Jr.

"Yesterday I dared to struggle. Today I dare to win."
–Bernodette Devlin

"Patience and perseverance have a magical effect before which difficulties disappear and obstacles vanish."
–John Quincy Adams

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Identify, understand, and appreciate the various air control valves required for proper functioning of the pneumatic systems.

☑ Understand and explain the construction, operation, and application of various directional control valves (such as check valves, two-way, three-way, four-way DC valves, shuttle valves, and quick exhaust valves).

☑ Understand and explain the construction, operation, and application of air pressure regulator and flow control valve.

☑ Identify and describe the construction, operation, and application of various types of pneumatic cylinders.

☑ Identify and describe the costruction, operation, and application of various types of air motors.

CHAPTER

12

PNEUMATIC VALVES AND ACTUATORS

12.1. INTRODUCTION

Like in hydraulic systems, pneumatic systems also require control valves to direct and regulate the flow of air from compressor to the various load devices. As we know, in order to control the movement of pneumatic actuators, the compressed air has to be regulated, controlled, and reversed with a predetermined sequence. Also one has to control the pressure and flow rate of the working medium (compressed air) to produce the desired level of force and speed of actuators. These functions are achieved with the use of pneumatic valves.

We need to convert the pressure energy of air (called pneumatic energy) into mechanical energy to perform useful works. This function is accomplished by the devices known as pneumatic actuators. Like in hydraulic systems, pneumatic actuators also use both pneumatic cylinders and air motors. The pneumatic cylinders generate motion in a straight line to perform the work. The air motors generate rotary output motion to perform the work.

In this chapter, we shall discuss the principle, construction, and application of various control valves and actuators employed in a pneumatic system.

PNEUMATIC VALVES

12.2. AIR CONTROL VALVES

12.2.1. Functions of Air Control Valves

The main functions of pneumatic valves are :

(*i*) To start and stop pneumatic energy;
(*ii*) To control the directional flow of compressed air;
(*iii*) To control the flow rate of the compressed air; and
(*iv*) To control the pressure rating of the compressed air.

12.2.2. Types of Air Control Valves

The pneumatic valves can be classified in many ways.

I. Classification based on their main function :

1. Directional control valves,

   (*i*) Check valves,
   (*ii*) Shuttle valves,
   (*iii*) Two-way D.C valves,
   (*iv*) Three-way D.C valves, and
   (*v*) Four-way D.C valves.

2. Pressure control valves, and
3. Flow control valves.

II. Classification based on their construction :

1. Poppet (or seat) type valve,
2. Sliding spool type valves, and
3. Rotary spool type valves.

Now we shall see some important air control valves in the following sections.

12.3. CHECK VALVES

12.3.1. What are Check Valves ?

✓ Check valves are the most commonly used and the simplest type of directional control valves.

✓ ***Functions :*** The check valves are used :

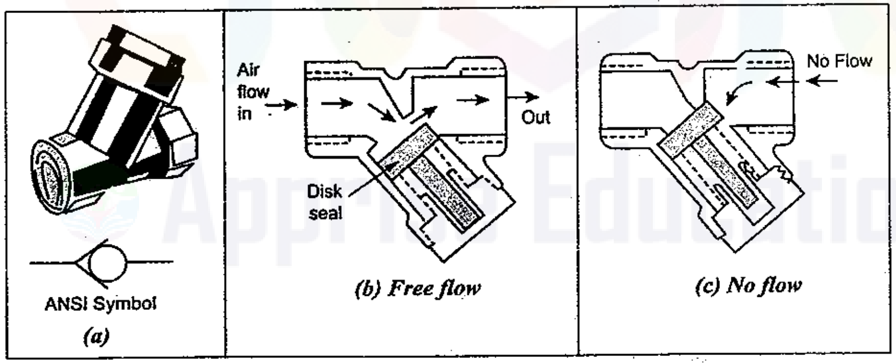
(*i*) to allow free flow of compressed air in only one direction, and

(*ii*) to prevent any flow of compressed air in the opposite direction.

✓ Since check valves block the reverse flow of the fluid, they are also known as ***non-return valves.***

12.3.2. Construction and Operation

The sectional view and ANSI symbol of pneumatic check valve are shown in Fig.12.1(*a*). The construction and operation of a typical pneumatic check valve is illustrated in Figs.12.1(*b*) and (*c*).



ANSI Symbol
(a)

(b) Free flow

(c) No flow

Fig. 12.1. Pneumatic check valve

As shown in Fig.12.1(*b*), when flow is in the forward direction, the compressed air pressure pushes the disk seal and thus the valve allows free flow. Instead, if flow is attempted in the opposite direction as shown in Fig.12.1(*c*), the compressed air pushes the disk seal in the closed position. Hence no flow is permitted in opposite direction.

12.4. DIRECTIONAL CONTROL VALVES

12.4.1. What are Directional Control Valves ?

✓ As the name suggests, *the function of a directional control valve (DCV) is to control the direction of flow in a pneumatic circuit.*

✓ The DCVs are used to start, stop and regulate the direction of air flow and to help in the distribution of air in the desired line.

✓ ***Types :*** As discussed in Section 7.6.2, the D.C valves can be classified in many different ways.

1. Based on the construction :

(*i*) Poppet (or seat) valves,

(*ii*) Sliding spool valves, and

(*iii*) Rotary spool valves.

2. Based on the number of ports present :

(*i*) Two way valves,

(*ii*) Three way valves, and

(*iii*) Four way valves.

12.4.2. Two-Way Valves

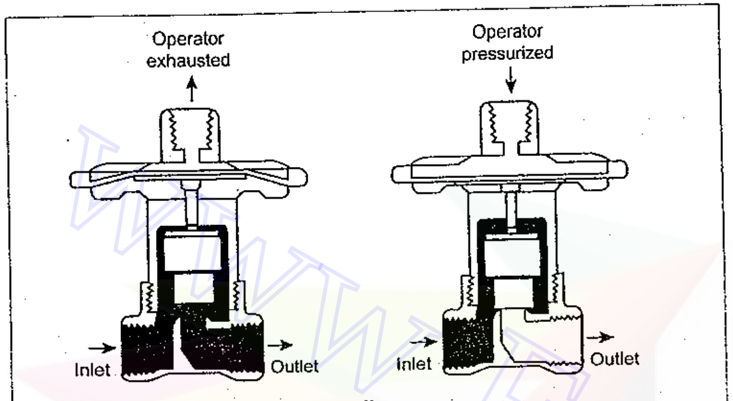
12.4.2.1. Construction and Operation

The construction and operation of an air-piloted (*i.e.*, air-operated), two-way pneumatic valve is illustrated in Fig.12.2.

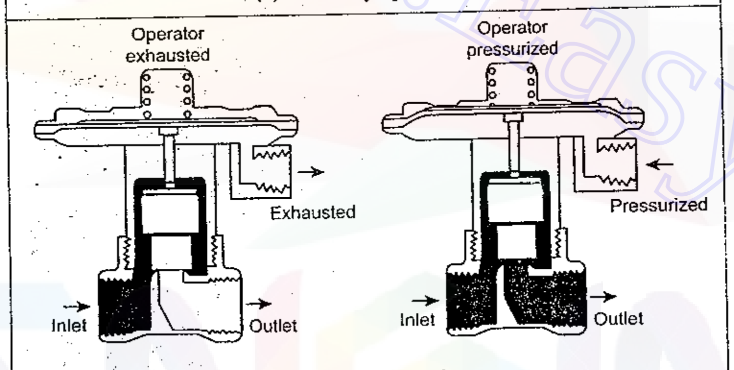
Basically two-way valve is an on-off type valve. This 2/2 way has two ports (a supply port and an exhaust port) and two positions (open and closed). As shown in Fig.12.2, 2/2 way valve is available to operate either normally open or normally closed conditions.

A normally open two-way valve (Fig.12.2(*a*)) permits flow in its normal or in its rest position and blocks flow when actuated. The normally closed valve (Fig.12.2(*b*)) block flow in its normal position and permits flow when actuated.

These valves have long life and can be used to handle dry and lubricated air.



(a) Normally open



(b) Normally closed

Fig. 12.2. Two-way, air-piloted valve

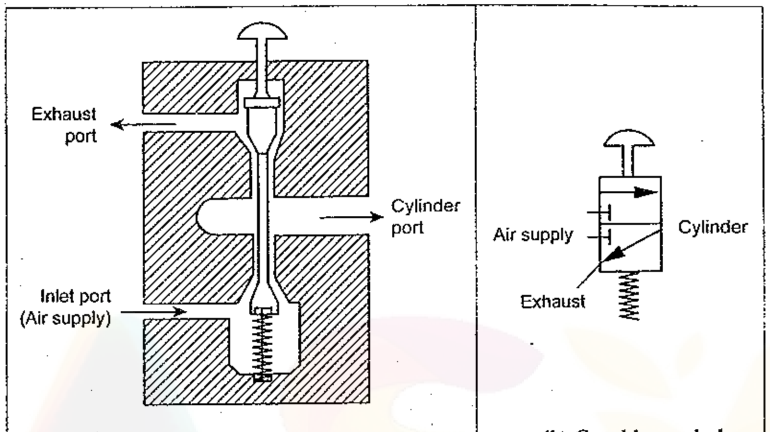
12.4.3. Three-Way Valves

The three-way type valves have three ports—an inlet, an exhaust, and a cylinder port.

12.4.3.1. Construction and Operation

The construction and operation of a typical poppet-type three-way two-position (*i.e.*, 3/2) pneumatic valve is illustrated in Fig.12.3(*a*). Fig.12.3(*b*) shows the graphic symbol of the 3/2 way valve.

As could be seen from Fig.12.3(*a*) that one flow port is connected to either of the other two ports. This valve may also be used to pressurise one port and exhaust the other port. Thus these valves can be used as a pilot relay to operate the other valves.



(a) (b) Graphic symbol

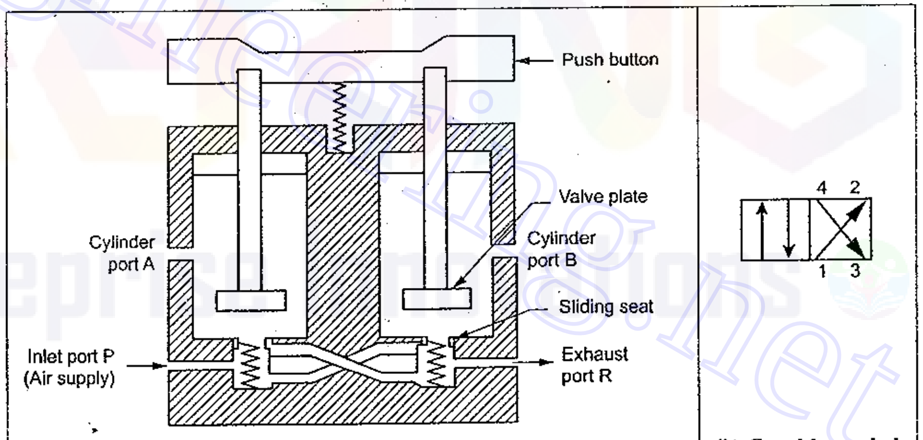
Fig. 12.3. 3/2 way DC valve

12.4.4. Four-Way Valves

The four way type valves have four ports—an inlet, an exhaust, and two cylinder ports.

12.4.4.1. Construction and Operation

The construction and operation of a typical valve-seat type four-way two-position (*i.e.*, 4/2) pneumatic valve is illustrated in Fig.12.4(*a*). Fig.12.4(*b*) shows the graphic symbol of the 4/2 way valve.



(a) (b) Graphic symbol

Fig. 12.4. 4/2 way DC valve

As shown in Fig.12.4, the inlet port P connects to cylinder ports A and B to exhaust port R. When the valve elements are actuated by means of the push button, they are unseated and port P connects to cylinder ports B and A to exhaust port R.

Note Generally two way DC valves are used as on-off type valves; three way DC valves are used to control single-acting linear actuators; and four way DC valves are used to control double-acting actuators.

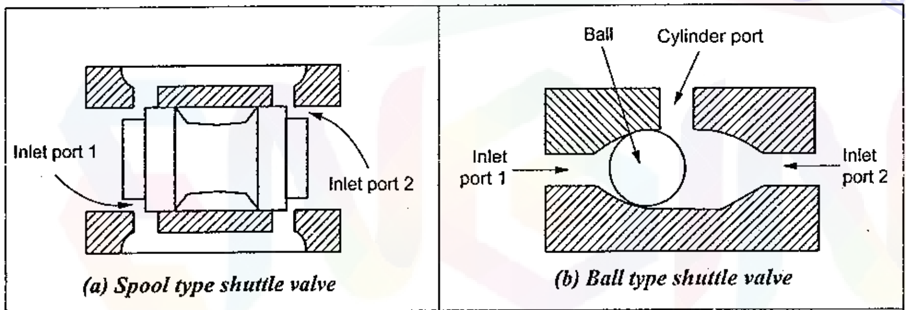
12.5. SHUTTLE VALVES

12.5.1. What are Shuttle Valves ?

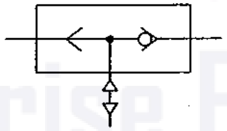
- ✓ *Shuttle valves, also known as* ***double check valves,*** *are used when control is required from more than one power source.*
- ✓ In other words, shuttle valves are used to select the higher of the two input pressures automatically and connects to output port. This valve is also known as 'OR GATE'.

12.5.2. Construction and Operation

The construction and operation of a typical three port spool-type shuttle valve is illustrated in Fig.12.5(*a*). The alternative ball-type shuttle valve for the same purpose is shown in Fig.12.5(*b*).



(a) Spool type shuttle valve *(b) Ball type shuttle valve*



(c) Graphic symbol

Fig. 12.5. Shuttle valve

As shown in Figs.12.5(*a*) and (*b*), this valve consists of two inlet ports and one outlet port. As long as pressure in the right inlet port is greater than the left, the spool (or ball) closes the left port. When pressure at the left port becomes greater than at the right, the spool (or ball) moves to the right, closing the right port and opening the left.

12.5.3. Graphic Symbol

Fig.12.5(*c*) shows the graphic symbol of a shuttle valve.

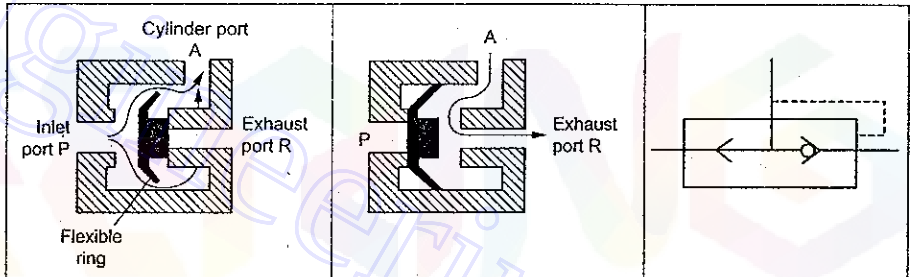
12.6. QUICK EXHAUST VALVE

12.6.1. What is a Quick Exhaust Valve ?

- ✓ A quick exhaust valve is a typical shuttle valve. *The quick (or fast) exhaust valve is used to exhaust the cylinder air to the atmosphere quickly.*
- ✓ It is basically used with spring return single-acting pneumatic cylinders to increase the piston speed of cylinders.
- ✓ The higher speed of piston in a cylinder is possible by reducing the resistance to flow of the exhausting air during motion of the cylinder. The resistance can be reduced by expelling the exhausting air to the atmosphere quickly by using a special valve. That's why this valve is known as a quick exhaust valve.

12.6.2. Construction and Operation

The construction and operation of a typical quick exhaust valve is shown in Fig.12.6. It consists of a movable disc and three ports—an inlet port (P), and exhaust port (R), and a cylinder port (A). Its working principle is very much similar to that of a shuttle valve.



(a) Air flows to cylinder from main line *(b) Air exhausts to atmosphere from cylinder* *(c) Graphic symbol*

Fig. 12.6. Quick exhaust valve

When the air flowing to the cylinder from the DC valve is applied at port P, then the flexible ring covers the exhaust port R, whereby the compressed air passes from port P to the cylinder through port A (Fig.12.6(*a*)).

But the return air from the cylinder pushes the flexible ring to cover the inlet port P, whereby the exhaust air immediately expelled to the atmosphere (Fig.12.6(*b*)). Thus the resistance to piston movement is reduced considerably and the speed of the piston in the cylinder is accelerated proportionately.

12.6.3. Graphic Symbol

Fig.12.6(*c*) shows the graphic symbol of a quick exhaust valve.

12.7. PRESSURE REGULATING VALVES

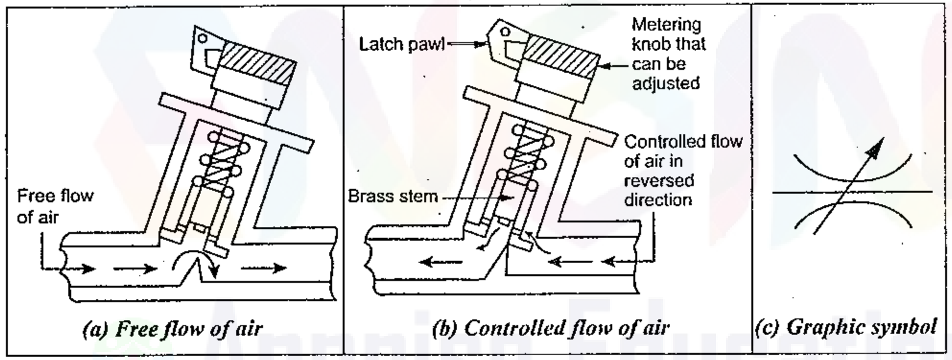
- ✓ As the name suggests, *the pneumatic pressure regulator is used to supply a prescribed reduced outlet pressure in a pneumatic circuit and to maintain it at a constant value.*
- ✓ Usually these pneumatic pressure regulators are installed at the inlet of the each separate pneumatic circuit. Sometimes they are installed within a circuit to provide two or more different pressure levels for separate portions of the circuit.
- ✓ The construction, operation, and function of a pressure regulator is already discussed in detail in Section 11.8.

12.8. FLOW CONTROL VALVE

*Flow control valves, also known as **volume-control valves**, are used to regulate the volumetric flow of the compressed air to different parts of a pneumatic system.*

12.8.1. Construction and Operation

The construction and operation of a typical spring-loaded disk-type flow control valve is illustrated in Fig.12.7.


Free flow of air
Latch pawl
Metering knob that can be adjusted
Controlled flow of air in reversed direction
Brass stem

(a) Free flow of air *(b) Controlled flow of air* *(c) Graphic symbol*

Fig. 12.7. Flow control valve

As shown in Figs.12.7(*a*) and (*b*), the spring loaded disk allows free flow in one direction and an adjustable or controlled flow in the opposite direction. A tapered brass stem controls the flow adjustment by controlling the flow through the cross hole in the disk.

12.8.2. Symbol

Fig.12.7(*c*) shows the graphic symbol of a flow control valve.

PNEUMATIC ACTUATORS

12.9. PNEUMATIC ACTUATORS

12.9.1. What are Pneumatic Actuators ?

- ✓ *Pneumatic actuators are the devices used for converting the pressure energy of air (also called pneumatic energy) into mechanical energy to perform useful work.*
- ✓ The pressurised air delivered by the air compressor is supplied to the pneumatic actuators, which converts the pressure energy of the air into mechanical energy. This mechanical energy is used to perform some useful work.
- ✓ Like hydraulic actuators, the pneumatic actuators also produce linear, rotary, or oscillating motion.

12.9.2. Types of Pneumatic Actuators

Based on the type of motion actuators produce, the pneumatic actuators are categorized into two :

1. Linear actuators (also called 'pneumatic cylinders'), and
2. Rotary actuators (also called 'air motors').

The pneumatic cylinders generate motion in a straight line to perform the work. The air motors generate rotary output motion to perform the work.

Note At the outset, the construction, working, and functions of hydraulic and pneumatic actuators are very much similar. But generally pneumatic actuators are of lighter construction and of lesser weight; this is because the fluid medium—air—can be used mostly for low or medium pressure applications only.

12.10. PNEUMATIC LINEAR ACTUATORS (PNEUMATIC CYLINDERS)

12.10.1. What are Pneumatic Cylinders ?

- ✓ *Pneumatic cylinders are the devices for converting the air pressure into linear mechanical force and motion.*
- ✓ The pneumatic cylinders are basically used for single-purpose applications such as clamping, stamping, transferring, branching, allocating, ejecting, metering, tilting, bending, turning and many other applications.

12.10.2. Types of Pneumatic Cylinders

The different classification scheme of the pneumatic cylinders are given below :

1. Based on the applications for which air cylinders are used :

- (*i*) Light duty air cylinders,
- (*ii*) Medium duty air cylinders, and
- (*iii*) Heavy duty air cylinders.

2. Based on the cylinder action :

- (*i*) Single-acting cylinders, and
- (*ii*) Double-acting cylinders.

3. Based on the cylinder's movement :

- (*i*) Rotating type air cylinders, and
- (*ii*) Non-rotating type air cylinders.

4. Based on the cylinder's design :

- (*i*) Through rod cylinders,
- (*ii*) Cushion end cylinders,
- (*iii*) Tandem cylinders,
- (*iv*) Double rod cylinders,
- (*v*) Telescoping cylinders, *etc*.

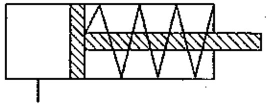
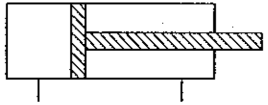
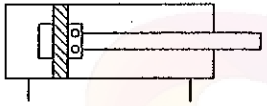
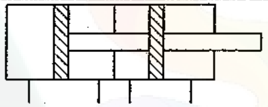
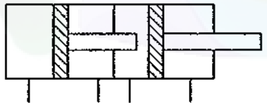
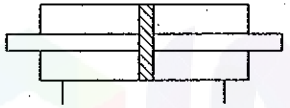
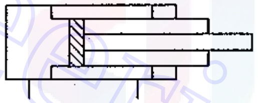
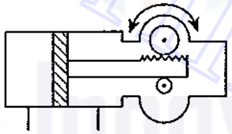
12.10.3. Single- and Double-Acting Air Cylinders

- ✓ As the name suggests, ***the single-acting air cylinders*** can deliver a force in only one direction. In these types, air only moves or pushes the piston in one direction and the piston is returned by means of an external spring or by gravity.
- ✓ In ***the double-acting air cylinders***, air pressure can be applied to either side of the piston, thereby providing a pneumatic force in both directions.
- ✓ The construction, working principle, graphic symbol, merits and demerits of single- and double-acting air cylinders are very much similar to that of the hydraulic cylinders. For more details, refer Sections 6.3 and 6.4.

12.10.4. Other Pneumatic Cylinders

Some of the basic pneumatic cylinder types and their brief descriptions are presented in Table 12.1.

Table 12.1. Some basic types of pneumatic cylinders

Sl.No.	Cylinder Type	Diagram	Description
1.	Single-acting cylinder		Air pushes the piston in one direction and the piston is returned by means of an external spring.
2.	Double-acting cylinder		The force exerted by the compressed air moves the piston in both directions.
3.	Cushion end cylinder		Cushioning is used in the end positions to prevent sudden damaging impacts.
4.	Tandem cylinder		Here two cylinders are arranged in series so that the force obtained from the cylinder is almost doubled.
5.	Dual linear cylinder (Three position cylinder)		Similar to tandem cylinder, but the piston and rod assemblies of a dual actuator are not fastened together as in the tandem cylinder.
6.	Double-rod cylinder (Through rod cylinder)		It has piston rods extending from both ends of the cylinder. It produces equal force and speed on both sides of the cylinder.
7.	Telescoping cylinder		It is a two-stage, double-acting telescopic cylinder; for more details refer Section 6.6.2.
8.	Turn cylinder (Rotary cylinder)		It has a piston rod having rack and pinion arrangement in such a manner that with linear movement of the piston rod, the worm wheel rotates at 45°, 90°, 180°, *etc*.

12.10.5. Rotating- and Non-rotating Type Air Cylinders

- ✓ ***Rotating-type air cylinders*** are used in applications requiring that the cylinder body can be connected to a rotating member while the air connections to the cylinder be in a stationary housing. Such cylinders are used on lathes, grinders, spinning machines and other machines with rotating spindles.

✓ ***Non-rotating type air cylinders*** are more widely used than rotating cylinders. Because the great majority of applications do not involve a rotating member.

12.11. PNEUMATIC ROTARY ACTUATORS (AIR MOTORS)

12.11.1. What are Air Motors ?

✓ *The function of an air motor (or a pneumatic rotary actuator) is to convert the pressure energy of the compressed air into rotary mechanical energy.*

✓ ***Types :*** Like hydraulic motors, air motors can also be classified based on their degree of angular movement as :

(*i*) Continuous rotary air motors, and

(*a*) Gear motors, (*b*) Vane motors, and (*c*) Piston motors.

(*ii*) Limited rotation air motors.

(*a*) Vane type, and (*b*) Piston type.

12.11.2. Continuous Rotary Air Motors

These air motors with unlimited angle of rotation (even upto 10,000 revolutions per minute) are most widely used to provide very high rotational speeds. The construction and operation of continuous rotary air motors are very much similar to that of the hydraulic motors discussed in Sections 6.10–6.12.

1. Gear motors : In the gear motors, rotary motion is produced by the unbalanced pneumatic forces on the gear teeth. Thus the torque is generated by the pressure of the air against the teeth profiles of the two meshed gear wheels.

2. Vane motors : In the vane motors, the pressurised air acting on the vanes cause them to rotate and thus developing the torque output. They are suitable for low speed applications than gear motors.

3. Piston motors : Piston motors are positive displacement motors which can develop an output torque at the shaft by allowing pressurised air to act on the pistons. The two types of piston motors are axial- and radial-piston motors.

12.11.3. Limited Rotation Air Motors

The limited rotation air motors provide rotary output motion over a finite angle. The standard rotations of the shaft of these motors are 94°, 184°, and 364°. The construction and operation of limited rotation air motors are very much similar to that of the hydraulic motors discussed in Section 6.13.

12.11.4. Applications of Air Motors

The important applications of air motors include conveyor belts, bench grinders, agitators and mixers, feeding devices, hoists, machine feeders, tool devices, vibrators, and pipe threaders.

REVIEW AND SUMMARY

✓ *In this chapter, the purpose, construction, operation, graphic symbols of various air control valves (i.e., pneumatic valves) and pneumatic actuators required for proper functioning of the pneumatic system have been discussed.*

✓ ***Pneumatic valves*** *are devices used to control pressure, flow direction, or flow rate in pneumatic circuits.*

✓ ***Types of air control valves :*** *Three basic types of air control valves, based on their function in the pneumatic system, are :*

1. *Directional control valves,*
2. *Pressure control valves, and*
3. *Flow control valves.*

✓ *The* ***check valves,*** *also known as* ***non-return valves,*** *are used to allow free flow of compressed air in only one direction, and to prevent any flow in the opposite direction.*

✓ *The function of a* ***directional control valve (DCV)*** *is to control the direction of flow in a pneumatic circuit.*

✓ ***Shuttle valves,*** *also known as* ***double check valves,*** *are used when control is required from more than one power source.*

✓ ***Quick exhaust valve*** *is used to exhaust the cylinder to the atmosphere quickly (to increase the piston speed of the cylinder).*

✓ *The* ***pneumatic pressure regulator*** *is used to supply a prescribed reduced outlet pressure in a pneumatic circuit and to maintain it at a constant value.*

✓ ***Flow control valves,*** *also known as* ***volume-control valves,*** *are used to regulate the volumetric flow of the compressed air to different parts of a pneumatic system.*

✓ ***Pneumatic actuators*** *are the devices used for converting the pressure energy of air (also called pneumatic energy) into mechanical energy to perform useful work.*

✓ ***Types of pneumatic actuators :***

1. *Linear actuators (also called 'pneumatic cylinders'), and*
2. *Rotary actuators (also called 'air motors').*

✓ ***The pneumatic cylinders*** *are the devices for converting the air pressure into linear mechanical force and motion.*

✓ *The function of an* ***air motor*** *is to convert the pressure energy of the compressed air into rotary mechanical energy.*

KEY TERMS ONE SHOULD REMEMBER

- **Pneumatic valves**
- **Air control valves**
- **Directional control valves**
  - **Check valves**
  - **Non-return valves**
  - **Two way valves**
  - **Three way valves**
  - **Four way valves**
  - **Shuttle valves**
  - **Quick exhaust valves**
- **Pressure regulating valves**
- **Flow control valves**
- **Volume control valves**
- **Pneumatic actuators**
- **Pneumatic cylinders**
  - **Single-acting cylinders**
  - **Double-acting cylinders**
  - **Cushion end cylinders**
  - **Tandem cylinders**
  - **Dual linear cylinders**
  - **Double-rod cylinder**
  - **Through rod cylinder**
  - **Telescoping cylinder**
  - **Turn cylinder**
  - **Rotary cylinder**
  - **Rotating cylinder**
  - **Non-rotating cylinder**
- **Air motors**
- **Continuous rotary air motors**
  - **Gear motors**
  - **Vane motors**
  - **Pump motors**
- **Limited rotation air motors**

REVIEW QUESTIONS

Short Answer Type Questions

On Air Control Valves

1. What are air control valves ? Write their functions.
2. Name the three basic types of air control valves based on their function.
3. What are the three types of air control valves based on their configuration ?
4. What is the function of a DC valve in a pneumatic system ?
5. What is a check valve ? What are its functions ?
6. Mention the application of a (*i*) 2 way DC valve, (*ii*) 3 way DC valve, and (*iii*) 4 way DC valve.
7. What is the purpose of a shuttle valve in a pneumatic circuit ?
8. What is the purpose of a quick exhaust valve ?
9. Draw the graphic symbol for the following air control valves :
   (*a*) Check valve, (*b*) Shuttle valve,
   (*c*) 4/2 DC valve, and (*d*) Quick exhaust valve.
10. What is the function of an air pressure regulator ?
11. What is the function of a flow control valve in a pneumatic circuit ?

On Pneumatic Actuators

12. What is the function of a pneumatic actuator ?

13. How can you classify the pneumatic actuators ?
14. How do pneumatic actuators differ from hydraulic actuators ?
15. What is the function of a pneumatic cylinder ?
16. Mention few applications of air cylinders.
17. Name different types of pneumatic cylinders.
18. Differentiate between a single-acting and a double-acting pneumatic cylinder.
19. What is the function of an air motor ? How does it differ from an air cylinder ?
20. Name the basic types of pneumatic rotary actuators. Which will provide the maximum degree of rotation ?
21. What do you mean by a limited rotation air motor ?
22. Mention few applications of air motors.

Essay Answer Type Questions

1. (*a*) With a neat sketch, explain the construction and operation of a check valve used in a pneumatic system.
   (*b*) Describe the construction and operation of a valve-seat type four-way, two-position directional control valve.
2. (*a*) Describe with the help of neat sketch the construction and operation of a shuttle valve in a pneumatic circuit.
   (*b*) What do you mean by quick exhaust valve ? Explain its working principle with a sketch.
3. Write short notes on the following with respect to pneumatic systems :
   (*a*) Pressure regulator, and (*b*) Flow control valve.
4. Write short notes on the following pneumatic cylinders :
   (*a*) Double-acting cylinders, (*b*) Tandem cylinders,
   (*c*) Through rod cylinders, and (*d*) Telescoping cylinders.
5. Write short notes on the following types of air motors :
   (*a*) Continuous rotary air motors, and
   (*b*) Limited rotation air motors.

□□

Chapter 13

Fluid Power Circuit Design

"What is the life we have lost in living?
What is the wisdom we have lost in knowledge?
Where is the knowledge we have lost in information?
Where is the information we have lost in data?"
– T.S. Eliot

"We could never learn to be brave and patient if there were only joy in the world."
– Helen Keller

"You gain strength, courage, and confidence by every experience in which you really stop to look fear in the face. You must do the thing which you think you cannot do."
– Eleanor Roosevelt

Learning Objectives

While reading and after studying this chapter, you will be able to:

- ☑ Understand and design a variety of fluid power circuits.
- ☑ Describe and design the variety of hydraulic circuits including regenerative circuit, sequencing circuits, synchronizing circuits, fail-safe circuits, and speed control circuits.
- ☑ Discuss and design the variety of pneumatic circuits including control of single- and double-acting air cylinders, semi-automatic and automatic material handling circuits, sequencing circuits, and speed control circuits.
- ☑ Appreciate the advantages of using hydropneumatic circuits.
- ☑ Describe the operation of air-over-oil circuits.
- ☑ Compare between hydraulics, pneumatics, and hydropneumatics systems.
- ☑ Understand the design of pneumatic logic circuits using cascade method.

CHAPTER 13

Fluid Power Circuit Design

13.1. INTRODUCTION

So far, we have discussed about the fundamentals and system components that are related to hydraulic and pneumatic systems. In this chapter, we shall discuss about how basic hydraulic and pneumatic circuits are designed and constructed. Fluid power circuits are drawn by using graphical symbols of components just like in electrical circuit diagrams. In a fluid power circuit, various components such as pumps (compressor in case of pneumatic circuits), actuators and control valves are arranged in a systematic manner to perform useful task. Also it is mandatory for the fluid power engineers or technicians to have a knowledge of fluid power components and how they operate in fluid power circuits.

In this chapter, we shall discuss a variety of hydraulic, pneumatic, and pneumo-hydraulic circuits so as to better understand the basic design features of simple fluid power circuits.[†]

HYDRAULIC CIRCUITS

13.2. HYDRAULIC CIRCUITS

13.2.1. What is a Hydraulic Circuit ?

- ✓ *A hydraulic circuit may be defined as the graphic representation of the hydraulic components in a hydraulically operated machine.*
- ✓ In other words, a hydraulic circuit is an arrangement of interconnected components (such as pumps, actuators, control valves, and pipings), selected to achieve the desired work output.

13.2.2. Essential Components Required for a Hydraulic Circuit Design

For any hydraulic circuit design, the following hydraulic components are essential :

*1. **Hydraulic power pack :*** It consists of the pump, drive motor, mechanical couplings, oil reservoir, strainers, filters, coolers, *etc.*

*2. **Hydraulic control elements :*** They include various types of directional control valves, pressure control valves, flow control valves, electrical control valves, *etc.*

[†] Since fluid power circuits are developed with the use of components' graphic symbols, therefore the readers should be familiar and thorough with the fluid power symbols before they study fluid power circuits.

3. ***Power drive units (or actuators) :*** They are hydraulic cylinders and hydraulic motors.

4. ***System accessories :*** They include pipes and other fluid conductors, accumulators, boosters, pressure and temperature gauges, filters, *etc.*

13.2.3. Factors To Be Considered

The four important factors should be considered while designing any fluid power (hydraulic/pneumatic) circuit are :

1. Safety of operation,
2. Performance of desired function,
3. Efficiency of operation, and
4. Cost.

13.3. CONTROL OF A SINGLE-ACTING HYDRAULIC CYLINDER

13.3.1. Circuit

The circuit[†] of a two-position, three-way, manually operated, spring-offset directional control valve is illustrated in Fig.13.1. This circuit can be used to control the operation of single-acting cylinder. This circuit has a reservoir, a pump, a pressure relief valve, a 3/2 DC valve, and a single-acting cylinder.

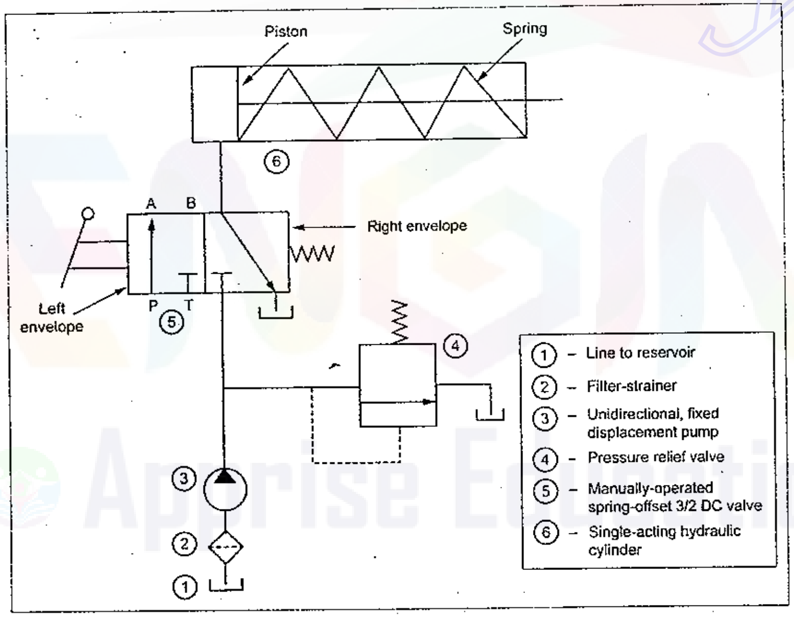

Piston
Spring
⑥
A
B
Right envelope
Left envelope
P
T
⑤
④
③
②
①
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Manually-operated spring-offset 3/2 DC valve
⑥ – Single-acting hydraulic cylinder

Fig. 13.1. Control of a single-acting hydraulic cylinder

[†] Remind yourself that all fluid power circuits should be drawn with all components shown in their unactuated position.

13.3.2. Operation

Extension : When the 3/2 DC vale is manually shifted to the left mode (*i.e.*, left envelope flow path configuration), the oil flows from the pump to blind end of cylinder. This pump flow extends the cylinder. Once full extension is over, the 3/2 DC valve is shifted to the right envelope.

Retraction : When the 3/2 DC valve is shifted to the right mode, the pump flow is diverted to the tank via the pressure relief valve. Now the spring in the cylinder retracts the piston to send the oil back to the tank.

13.4. CONTROL OF A DOUBLE-ACTING HYDRAULIC CYLINDER

13.4.1. Circuit

Fig.13.2 illustrates a circuit that can be used to control a double-acting hydraulic cylinder. This circuit uses a three-position, four-way, manually operated directional control valve (tandem position) and a double-acting cylinder.

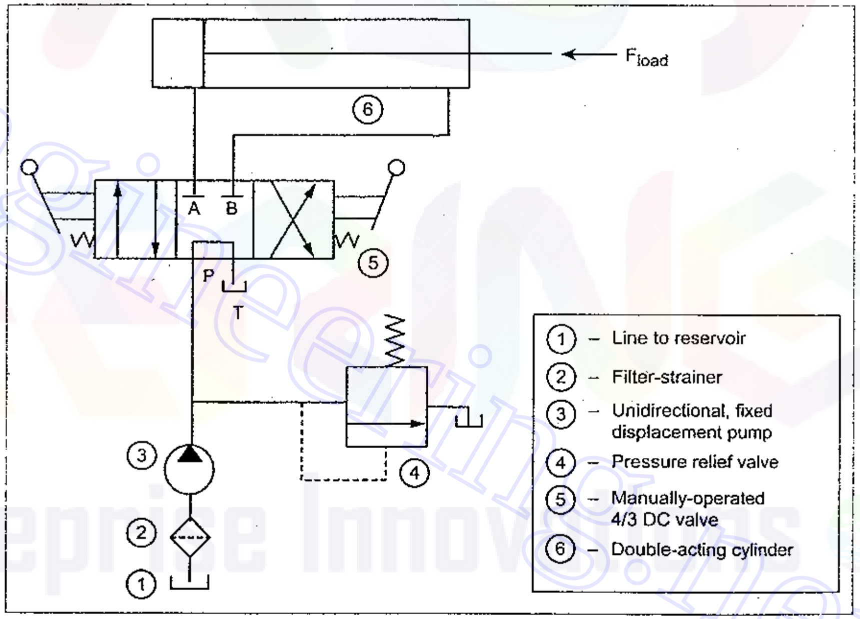

F_{load}
⑥
A
B
P
T
⑤
④
③
②
①
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Manually-operated 4/3 DC valve
⑥ – Double-acting cylinder

Fig. 13.2. Control of a double-acting hydraulic cylinder

13.4.2. Operation

Extension : When the 4/3 DC valve is manually shifted to the left mode (*i.e.*, left envelope flow path configuration), oil from the pump flows to the blind end of cylinder. As oil flows from port P through port A, the cylinder is extended against the load force F_{load}. At the same time, the oil in the rod side of the cylinder flows back freely to the tank (via the 4/3 valve from port B through port T).

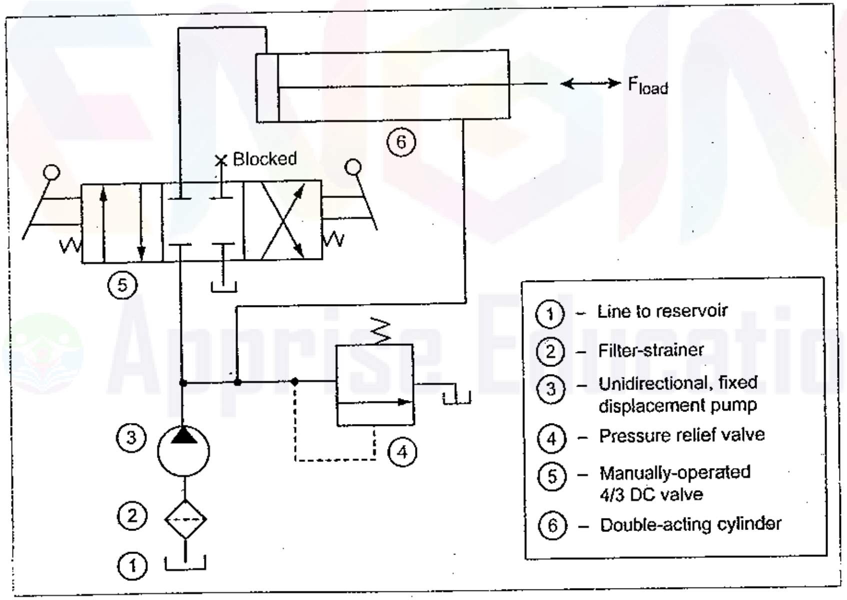
Retraction : At the end of extension stroke, the 4/3 DC valve is manually shifted to the right envelope. When DCV is shifted to the right mode, the oil from the pump flows to the rod side of the cylinder. As oil flows from port P through port B, the cylinder is retracted. At the same time, oil in the blank end flows back freely to the tank (via the flow path from port A to port T).

Cylinder locking : When the 4/3 DC valve is shifted to the centre position (*i.e.*, spring centered position in tandem design), the pump flow completely goes to tank and hence the cylinder is hydraulically locked.

13.5. REGENERATIVE CIRCUIT

A regenerative circuit is used to speed up the extending speed of the double-acting cylinder.

13.5.1. Circuit



Fload
Blocked
6
5
3
2
1
4
1 – Line to reservoir
2 – Filter-strainer
3 – Unidirectional, fixed displacement pump
4 – Pressure relief valve
5 – Manually-operated 4/3 DC valve
6 – Double-acting cylinder

Fig. 13.3. Regenerative circuit

Fig.13.3 illustrates a regenerative circuit that can be used to speed up the extending speed of the double-acting cylinder. This circuit uses a manually-operated, three position, four way directional control valve (closed center position), and a double-acting cylinder. It should be noted in this circuit that the pipelines to the cylinder are connected in parallel and one of the ports of the DCV is blocked.

13.5.2. Operation

Extension : When the 4/3 DC valve is shifted to the left mode, the oil flows from the pump to the blind end of the cylinder. This pump flow extends the cylinder.

Retraction : When the 4/3 DC valve is shifted to the right mode, the oil from the pump bypasses the DC valve and enters into the rod end of the cylinder. Oil in the blank end drains back to the tank through the DC valve as the cylinder retracts.

13.5.3. Why is Extension Stroke Faster than Retraction Stroke in the Regenerative Circuit ?

The speed of extension in the regenerative circuit is greater than that for a regular double-acting cylinder. But the speed of retraction is similar to the regular double-acting cylinder. This is because oil flow from the rod end (Q_R) regenerates with the pump flow (Q_P) to provide a total flow rate (Q_T), which is greater than the pump flow rate to the blank end of the cylinder.

13.5.4. Ratio of Extending and Retracting Speeds

Let Q_P = Pump flow rate,

Q_R = Flow from the rod end,

Q_T = Total flow rate,

$v_{P_{ext}}$ = Extending speed of piston,

$v_{P_{ret}}$ = Retracting speed of piston,

A_p = Cross-sectional area of piston,

A_r = Cross-sectional area of rod, and

P = Pressure setting of the relief valve.

$$\text{Then, regenerative cylinder extending speed} \Big\} \; v_{P_{ext}} = \frac{Q_P}{A_r} \qquad \ldots (13.1)$$

$$\text{Regenerative cylinder retracting speed} \Big\} \; v_{P_{ret}} = \frac{Q_P}{A_p - A_r} \qquad \ldots (13.2)$$

Dividing equation (13.1) by (13.2), and simplifying, we get

$$\text{Regenerative cylinder extending to retracting speed ratio} \Big\} \; \boxed{\frac{v_{P_{ext}}}{v_{P_{ret}}} = \frac{A_p}{A_r} - 1} \qquad \ldots (13.3)$$

$$\left.\begin{array}{r}\text{Also, Regenerative cylinder extending}\\ \text{load-carrying capacity}\end{array}\right\} F_{load} = P \cdot A_r \qquad \ldots (13.4)$$

From equation (13.3), it may be noted that when the piston area equals two times the rod area, both the extending and retracting speeds are equal.

Example 13.1 ***A double-acting cylinder is hooked up in the regenerative circuit of Fig.13.3. The relief valve setting is 100 bars. The piston area is 180 cm² and the rod area is 60 cm². If the pump flow is 0.0015 m³/s, find the cylinder speed and load-carrying capacity for the (i) extending stroke, and (ii) retracting stroke.***

Given Data : $P = 100 \text{ bars} = 100 \times 10^5 \text{ N/m}^2$; $A_p = 180 \text{ cm}^2$; $A_r = 60 \text{ cm}^2$;
$Q_P = 0.0015 \text{ m}^3/\text{s}$.

☺ ***Solution :***

(a) For extending stroke :

$$\text{Cylinder speed, } v_{P_{ext}} = \frac{Q_P}{A_r} = \frac{0.0015}{60 \times 10^{-4}} = \mathbf{0.25 \text{ m/s}} \quad \textbf{Ans.} ☜$$

$$\text{Load-carrying capacity, } F_{load_{ext}} = P \times A_r = (100 \times 10^5)(60 \times 10^{-4})$$

$$= \mathbf{60 \text{ kN}} \quad \textbf{Ans.} ☜$$

(b) For retracting stroke :

$$\text{Cylinder speed, } v_{P_{ret}} = \frac{Q_P}{A_p - A_r} = \frac{0.0015}{(180 \times 10^{-4} - 60 \times 10^{-4})}$$

$$= \mathbf{0.125 \text{ m/s}} \quad \textbf{Ans.} ☜$$

$$\text{Load-carrying capacity, } F_{load_{ret}} = P(A_p - A_r)$$

$$= (100 \times 10^5)(180 - 10^{-4} - 60 \times 10^{-4})$$

$$= \mathbf{120 \text{ kN}} \quad \textbf{Ans.} ☜$$

13.6. HYDRAULIC CIRCUIT FOR MACHINE TOOL APPLICATIONS

As we know many machine tool applications (such as drilling machine application) require faster extension of the cylinder (say, faster extension of drill spindle). This can be achieved by making rapid extension of the cylinder by regeneration.

13.6.1. Circuit

Fig.13.4 illustrates a circuit that can be used to produce a rapid extension of the cylinder (drill spindle) in a drilling machine application. This circuit uses a 4/3 DC valve (open centered position) and a double acting cylinder.

13.6.2. Operation

Left mode position : When the 4/3 DC valve is shifted to the left envelope flow path configuration, ***the cylinder extends*** in the same manner as that of a regular double-acting cylinder.

Right mode position : When the 4/3 DC valve is shifted to the right envelope flow path configuration, ***the cylinder retracts*** in the same manner as that of a regular double-acting cylinder.

Spring-centered position : When the 4/3 DC valve is shifted to the spring centered position, the oil from the rod end regenerates with the pump flow entering to the blank end. This effectively increases pump flow to the blank end of the cylinder. *Thus the spring-centered position gives rapid extension of the cylinder (drill spindle).*

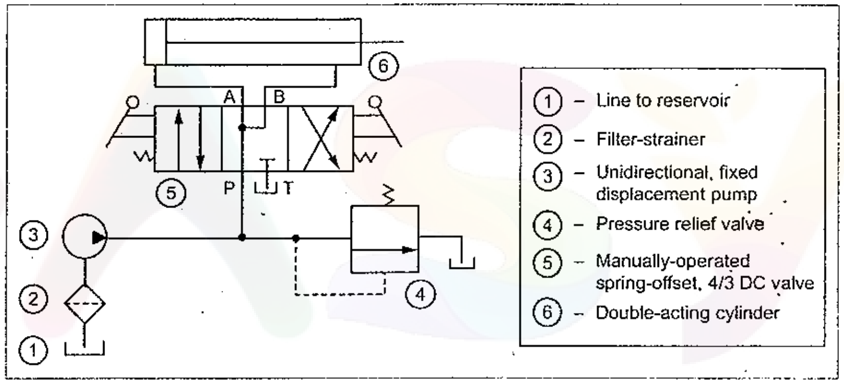

A
B
P
T
⑥
⑤
③
②
①
④
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Manually-operated spring-offset, 4/3 DC valve
⑥ – Double-acting cylinder

Fig. 13.4. Hydraulic circuit for drilling machine application

13.7. PRESSURE INTENSIFIER CIRCUIT IN PUNCHING PRESS APPLICATION

As we have already discussed in Section 8.14.1, with the use of a pressure intensifier one can eliminate a high-pressure pump in the punching press application. For more details on this intensifier circuit, refer Chapter 8, Section 8.14.1.

13.8. SEQUENCING OF TWO DOUBLE-ACTING CYLINDERS

As we know sequence valves are used extensively for sequencing operations when two or more cylinders are involved. These valves which are usually spring loaded, have been described already in Chapter 7, Section 7.19. The following circuit shows the use of a sequence valve in a two double-acting cylinder.

13.8.1. Circuit

Fig.13.5 illustrates a circuit that uses two sequence valves to control the sequence of operations of two double-acting cylinders. This circuit has a manually-operated, spring-centered 4/3 DC valve, two sequencing valves, two check valves, and a pressure relief valve. Let us take that cylinder-1 is used to clamp the workpiece and cylinder-2 is to perform punching; and the sequence of operation as clamping first and then punching.

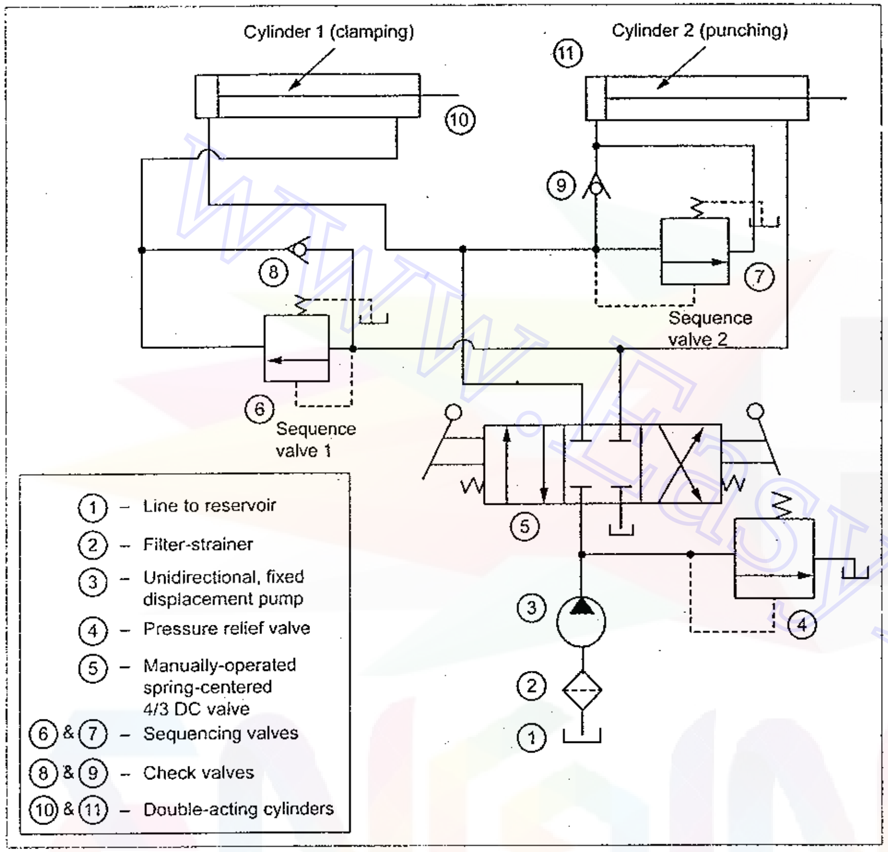

Cylinder 1 (clamping)
Cylinder 2 (punching)
⑩
⑪
⑨
⑧
⑦
Sequence valve 2
⑥
Sequence valve 1
⑤
③
④
②
①
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Manually-operated spring-centered 4/3 DC valve
⑥ & ⑦ – Sequencing valves
⑧ & ⑨ – Check valves
⑩ & ⑪ – Double-acting cylinders

Fig. 13.5. Hydraulic cylinder sequence circuit (for clamping and punching operations)

13.8.2. Operation

Left mode position : When the 4/3 DC valve is shifted manually to the left envelope flow path configuration, the cylinder-1 extends completely and the workpiece is clamped. Once the cylinder-1 reaches its end of the stroke, pressure is increased and sequence valve 1 opens and the oil starts to flow into the cylinder-2. Now the cylinder-2 extends to drive a spindle to do punching operation in the workpiece.

Right mode position : When the 4/3 DC valve is shifted to the right mode, the cylinder-2 retracts. Once the cylinder-2 retracts completely, the sequence valve 2 opens and the oil starts to flow into the cylinder-1. It causes the cylinder-1 to retract and hence the unclamping of workpiece is achieved.

Spring-centered position : When the 4/3 DC valve is shifted to the spring-centered position, the oil drains back to the tank through the pressure relief valve. Thus during the spring-centered position, both cylinders are hydraulically locked.

13.9. AUTOMATIC CYLINDER RECIPROCATING SYSTEM (Continuous Reciprocation Circuit)

The sequence valves can also be used to produce continuous reciprocation of a hydraulic cylinder.

13.9.1. Circuit

Fig.13.6 illustrates a circuit that produces automatic reciprocation of the hydraulic cylinder. This can be achieved by using two sequence valves and a pilot pressure operated spring-centered 4/3 DC valve.

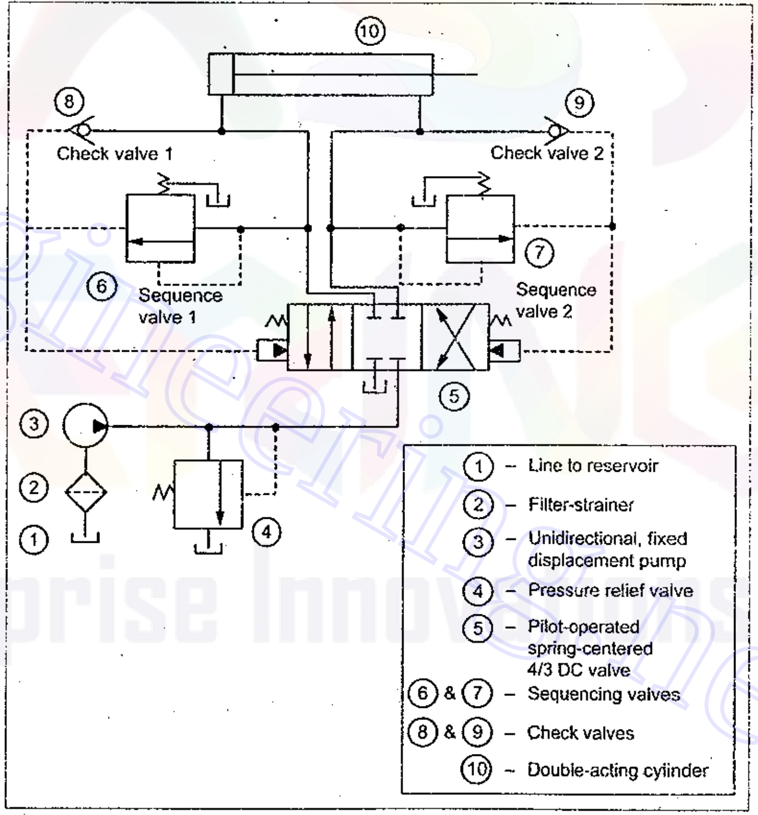

⑩
⑧
⑨
Check valve 1
Check valve 2
⑥
Sequence valve 1
⑦
Sequence valve 2
⑤
③
②
①
④
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Pilot-operated spring-centered 4/3 DC valve
⑥ & ⑦ – Sequencing valves
⑧ & ⑨ – Check valves
⑩ – Double-acting cylinder

Fig. 13.6. Automatic cylinder reciprocating system

13.9.2. Operation

Retraction : When the 4/3 DC valve is shifted to the left envelope flow path configuration, oil flows from the pump to the rod end of the cylinder. This pump flow retracts the cylinder. The check valve 1 prevents shifting of the 4/3 DC valve until the full retraction stroke completes. As the piston reaches its end of stroke, the pressure builds up in the sequence valve 1 and it opens. This allows the pilot pressure signal to shift the DC valve to the right mode.

Extension : When the pilot signal shifts the 4/3 DC valve to the right mode, the oil flows to the blind end of the cylinder. This pump flow extends the cylinder. The check valve 2 prevents shifting of the DC valve until the full extension stroke completes. As the piston reaches its end of stroke, the pressure builds up in the sequence valve 2 and it opens. This allows the pilot pressure signal to shift the DC valve to the left mode again.

Thus the sequence repeats and the cylinder reciprocates continuously.

13.10. HYDRAULIC CYLINDER SYNCHRONIZING CIRCUITS

There are many industrial applications require nearly perfect synchronization of movement of two or more cylinders in order to complete some phase of operation. To accomplish the identical task from the cylinders at the same rate, synchronizing circuits are employed. This synchronization can be achieved in many ways such as (*i*) By using double-end cylinders in series, (*ii*) By using mechanically linked pistons, (*iii*) By using hydraulic motors as metering devices, (*iv*) By using flow control valves, (*v*) By using air-hydraulic cylinders in series, *etc*.

Now we shall discuss how synchronization is achieved using the double-end cylinders in series.

13.10.1. Synchronizing Hydraulic Cylinders Connected in Series

13.10.2. Circuit

Fig.13.7 illustrates a circuit to synchronize two cylinders by connecting them in series. This circuit uses a solenoid-operated, spring-offset 4/3 DC valve and two double-acting hydraulic cylinders.

13.10.3. Operation

Extension of cylinders 1 and 2 : When the 4/3 DC valve is shifted to the left envelope flow path configuration, oil flows from the pump to the blind end of cylinder 1 and thus the cylinder 1 extends. At the same time, oil from the rod end of cylinder 1 is forced to the blind end of cylinder 2 and thus the cylinder 2 also extends. Now the oil returns to the tank from the rod end of cylinder 2 via the DC valve. Once full extension of cylinders 1 and 2 are over, the DC valve is shifted to the right mode.

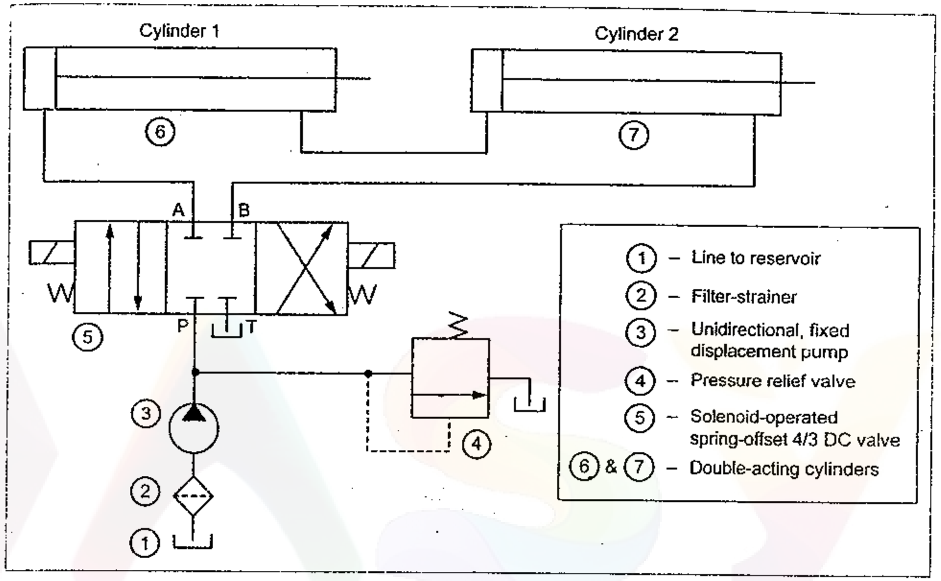

Cylinder 1
Cylinder 2
⑥
⑦
A
B
P
T
W
W
⑤
③
②
①
④
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Solenoid-operated spring-offset 4/3 DC valve
⑥ & ⑦ – Double-acting cylinders

Fig. 13.7. Synchronizing hydraulic cylinders by connecting them in series

Retraction of cylinders 1 and 2 : When the 4/3 DC valve is shifted to the right mode, oil flows from the pump to the rod end of cylinder 2 and thus the cylinder 2 retracts. At the same time, oil from the blind end of cylinder 2 is forced to the rod end of cylinder 1 and thus the cylinder 1 also retracts. Now the oil returns to the tank from the blind end of cylinder 1 via the DC valve.

Thus both extension and retraction operations of both cylinders are synchronized by connecting them in series. But for the two cylinders to be synchronized, the piston area of cylinder 2 should be equal to the difference between the areas of the piston and rod for cylinder 1.

13.11. SPEED CONTROL CIRCUITS

13.11.1. Speed Control of a Hydraulic Cylinder

As we have discussed in Section 7.20, flow control valves are used to control the speed of hydraulic cylinders. It should be noted that the location of flow control valve with respect to other components in a circuit will have effect on the characteristics of the circuit performance. The three basic types of locations of the flow control valve in any hydraulic circuit are :

1. Meter-in circuit,
2. Meter-out circuit, and
3. Bleed-off circuit

Now we shall discuss meter-in and meter-out types of speed control of hydraulic cylinders in the following sections.

13.11.2. Meter-in Speed Control of Hydraulic Cylinder

13.11.2.1. Circuit

Fig.13.8 illustrates a meter-in circuit that can be used to control the speed of a hydraulic cylinder using a flow control valve. This circuit uses a manually-operated spring-offset 4/2 DC valve and a flow control valve. In this meter-in circuit type, the flow control valve is located in the line leading to the inlet port of the cylinder, as shown in Fig.13.8.

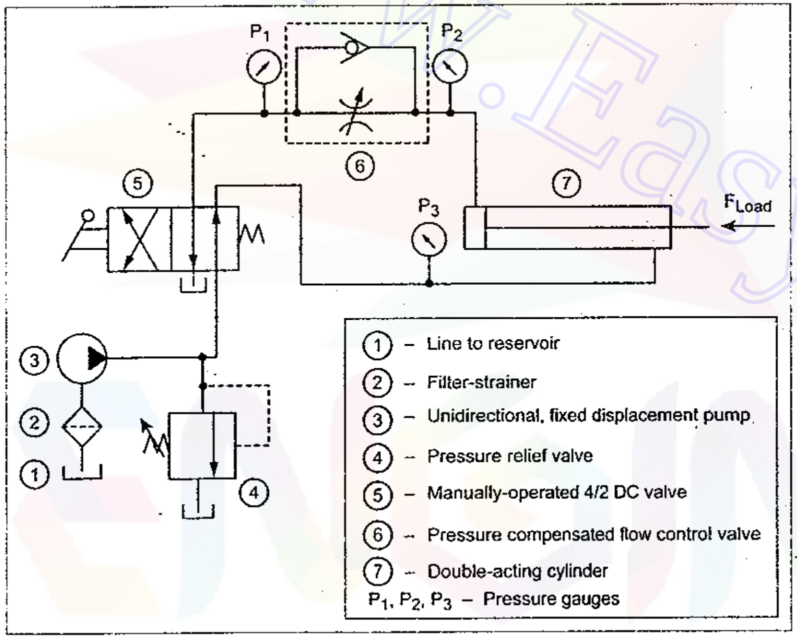

P1
P2
P3
5
6
7
F Load
3
2
1
4
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Manually-operated 4/2 DC valve
⑥ – Pressure compensated flow control valve
⑦ – Double-acting cylinder
P1, P2, P3 – Pressure gauges

Fig. 13.8. Meter-in speed control of hydraulic cylinder using flow control

13.11.2.2. Operation

Extension : When the 4/2 DC valve is mechanically shifted to its left mode, oil flows from the pump to the blind end of the cylinder via the flow control valve. This pump flow extends the cylinder. Here it can be noted that the extending speed of the cylinder depends on the setting of the flow control valve. Thus the extending speed of the cylinder can be increased or decreased just by regulating the flow of fluid in the flow control valve.

Retraction : When the 4/2 DC valve is shifted to its right mode, oil flows from the pump to the rod end of the cylinder and hence the cylinder retracts. The oil from the blind end of the cylinder drains back to the oil tank through the check valve as well as the flow control valve.

13.11.3. Meter-out Speed Control of Hydraulic Cylinder

13.11.3.1. Circuit

Fig.13.9 illustrates a meter-out circuit to control the speed of a hydraulic cylinder. In this meter-out circuit type, the flow control valve is located in the outlet line of the hydraulic cylinder, as shown in Fig.13.9.

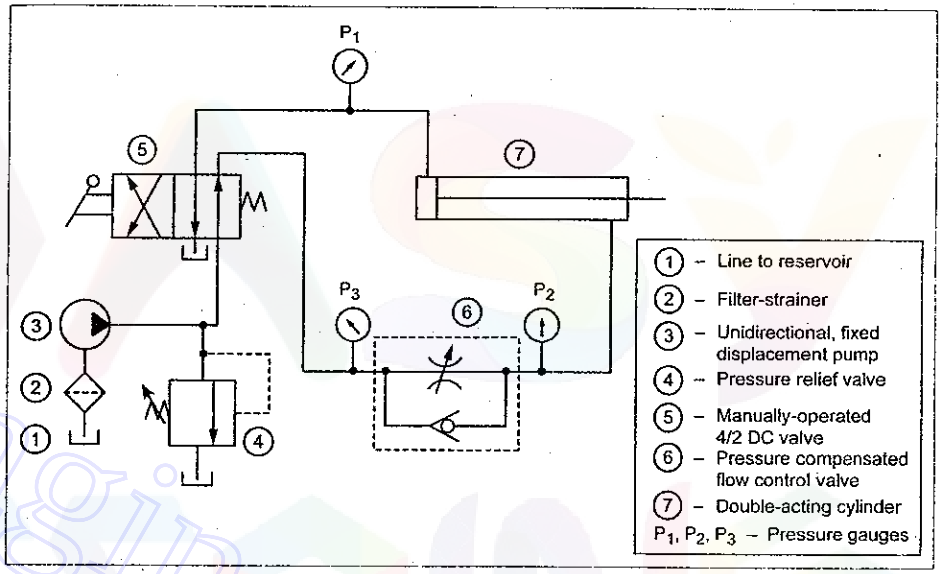

P1
5
7
P3
6
P2
3
2
1
4
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Manually-operated 4/2 DC valve
⑥ – Pressure compensated flow control valve
⑦ – Double-acting cylinder
P1, P2, P3 – Pressure gauges

Fig. 13.9. Meter-out speed control of hydraulic cylinder using flow control

13.11.3.2. Operation

The operation meter-out circuit is very much similar to that of the meter-in circuit. The only difference is that meter-out flow control system controls the oil flow rate out of the cylinder. In other words, meter-out circuit controls the retracting speed of the cylinder.

Note ✓ ***Meter-in circuits*** are generally used when the external load opposes the direction of motion of the hydraulic cylinder. An example of this situation is the case of a hydraulic table feed on a surface grinder.

✓ ***Meter-out circuits*** are commonly used when the external load acts in the same direction of motion of the hydraulic cylinder. An example of this situation is the case of a load acting downward on the piston rod of a vertical cylinder. To avoid the erratic downward motion of the load, a back pressure is maintained in the exhaust side of the cylinder by using meter-out circuit.

✓ In the ***bleed-off circuit,*** the flow control valve is connected with its outlet port which is connected to the reservoir. The flow control valve controls flow to the cylinder by diverting an adjustable amount of pump's flow to the reservoir. Since oil delivered to the cylinder does not have to flow through the flow control valve, this circuit avoids the need of dumping excess oil through the relief valve.

13.12. SPEED CONTROL OF A HYDRAULIC MOTOR

13.12.1. Circuit

Fig.13.10 illustrates a circuit that can be used to control the speed control of a hydraulic motor. This circuit uses a pressure-compensated flow control valve and a manually-operated spring-centered 4/3 DC valve (tandem design).

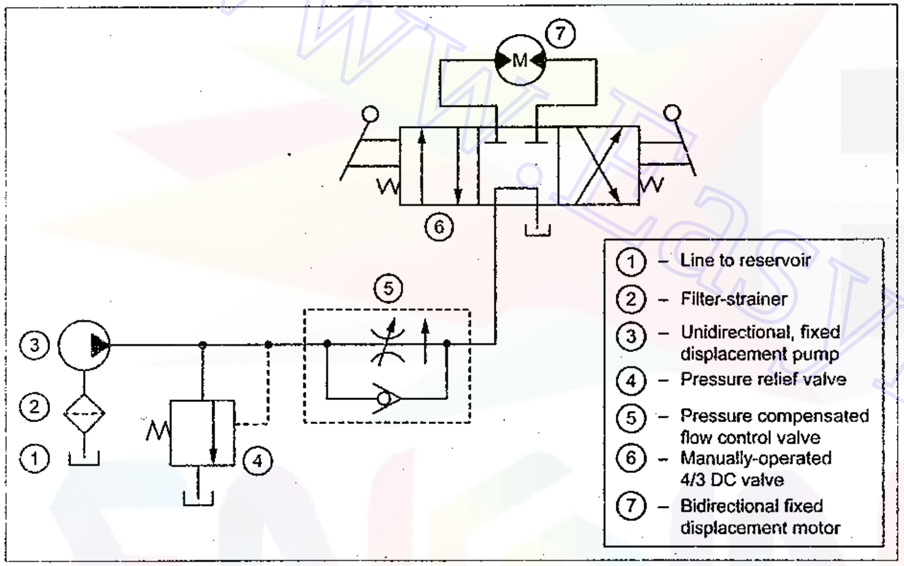

7
M
W
W
6
5
3
2
1
4
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Pressure compensated flow control valve
⑥ – Manually-operated 4/3 DC valve
⑦ – Bidirectional fixed displacement motor

Fig. 13.10. Speed control of hydraulic motor using flow control valve

13.12.2. Operation

Left envelope position : When the 4/3 DC valve is manually shifted to the left mode, the oil flows from the pump to the hydraulic motor through the flow control valve. This oil flow rotates the motor in one direction. Here it may be noted that the speed of the hydraulic motor can be varied infinitely by adjusting the setting of the throttle of the flow control valve. The excess oil (while controlling the flow in the flow control valve) is returned to the oil tank through the pressure relief valve.

Right envelope position : When the 4/3 DC valve is manually shifted to the right mode, the oil flow rotates the hydraulic motor in the opposite direction. Here also the motor speed can be varied infinitely by adjusting the setting of the throttle of the flow control valve.

Spring-centered position : When the 4/3 DC valve is shifted to its spring-centered position, the motor is hydraulically locked.

13.13. FAIL-SAFE CIRCUIT

Fail-safe circuits are designed to safeguard the operator, the machine, and the workpiece. These circuits prevent any possible injury to the operator or damage to the machine and the workpiece. One such fail-safe circuit is explained below.

13.13.1. Two Handed Safety Circuit

The two handed safety circuit is designed to protect an operator from accident.

13.13.2. Circuit

Fig.13.11 illustrates a typical two handed safety control circuit for safeguarding the operator from injury. This circuit uses a pilot-operated spring-offset 4/3 DC valve and two push buttons.

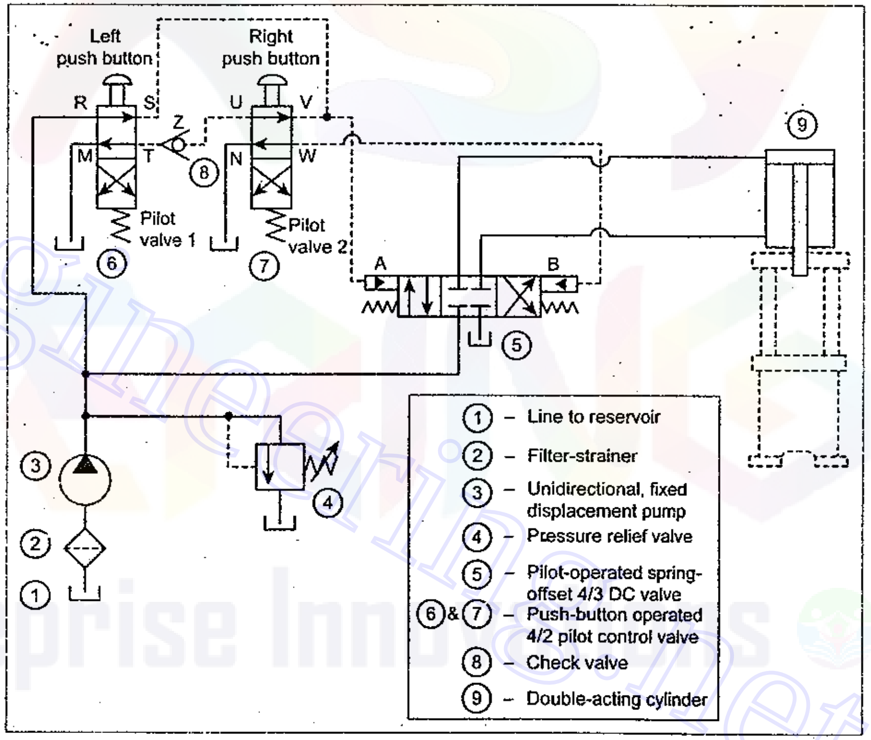

Left push button
Right push button
R
S
U
V
Z
M
T
N
W
8
9
Pilot valve 1
Pilot valve 2
6
7
A
B
5
3
4
2
1
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Pilot-operated spring-offset 4/3 DC valve
⑥&⑦ – Push-button operated 4/2 pilot control valve
⑧ – Check valve
⑨ – Double-acting cylinder

Fig. 13.11. Two handed safety control circuit

13.13.3. Operation

The circuit functions as follows :

1. When the 4/3 DC valve is in its centre position, the oil flow is diverted back to tank through the pressure relief valve. Therefore the cylinder is hydraulically locked.
2. When operator pushes down both left and right push buttons, the oil flows in through port R of pilot valve 1 and out through port S, then through port V of pilot valve 2 and out port U. But check valve Z stops flow. At the same time, the oil also flows to pilot connection A of 4/3 DC valve causing the DC valve to shift to its left mode. When the DC valve is shifted to its left mode, the oil from the pump flows into the blank end of the cylinder and thus the cylinder extends. ***Thus the extension of cylinder takes place only when the operator depresses both the push buttons.***
3. When the operator pushes the right push button only, oil flows in through port R to port S of pilot valve 1, then through port V to port N of pilot valve 2. Thus the oil is drained to the tank through the pilot valve 2. This allows the 4/3 DC valve to return to neutral position; thus the cylinder is hydraulically locked.
4. When the operator pushes the left push button only, oil flows in port R of pilot valve 1 and out port T, then unseats ball in check valve Z, then on to port U of pilot valve 2, and out port V. Oil follows the path of least resistance so it passes in port S of pilot valve 1, out port M and into sump. It does not build up enough pressure to keep pilot pressure on pilot connection A so 4/3 DC valve shifts back to neutral position; thus the cylinder is hydraulically locked.
5. When the operator releases both left and right push buttons, oil flows in port R of pilot valve 1 and out port T, then through check valve Z and into port U of pilot valve 2. Now the oil flows out port W into pilot connection B of 4/3 DC valve shifting its position to right mode. When the 4/3 DC valve is shifted to its right mode, the oil from the pump flows into the rod end of the cylinder and hence the cylinder retracts. ***Thus the retraction of cylinder takes place only when the operator releases both the push buttons.***

It may be noted that the operator cannot misuse this safety feature by pressing any one of the push buttons. In order to operate the circuit, the operator has to depress or release both the push buttons of the pilot valves 1 and 2.

Note The other hydraulic circuits such as accumulator circuits and intensifier accumulator circuits have been presented already in Chapter 8. For more details on accumulator circuits, refer Section 8.11; and on intensifier circuits refer Section 8.14.

PNEUMATIC CIRCUITS

13.14. PNEUMATIC CIRCUITS

13.14.1. What is a Pneumatic Circuit ?

✓ *A pneumatic circuit may be defined as the graphic representation of the pneumatic components in a pneumatically operated machine.*

✓ Pneumatic circuit diagrams can be drawn in similar fashion to the hydraulic circuit diagrams.

13.14.2. Pneumatic Circuits Vs Hydraulic Circuits

Though both hydraulic and pneumatic circuits are quiet similar, the two important differences are given below :

1. Unlike in hydraulic systems, pneumatic systems directly exhaust the used air from the air cylinder to the atmosphere. Therefore *the return lines are not required in pneumatic circuits.* This is depicted by a short dashed line leading from the exhaust port of each valve.
2. Since most pneumatic circuits use a centralized compressor as their source of energy, generally no input device (such as a pump in a hydraulic circuit) is shown in these circuits. Also the input to the circuit can be located at some convenient manifold, which leads directly into the FRL (Filter-Regulator-Lubricator) unit.

13.15. CONTROL OF A SINGLE-ACTING PNEUMATIC CYLINDER

13.15.1. Circuit

Fig.13.12 illustrates a simple pneumatic circuit of a single-acting air cylinder being controlled by a 3/2 DC valve. This circuit has a FRL unit, a push-button operated spring-return 3/2 DC valve, and a single-acting pneumatic cylinder.

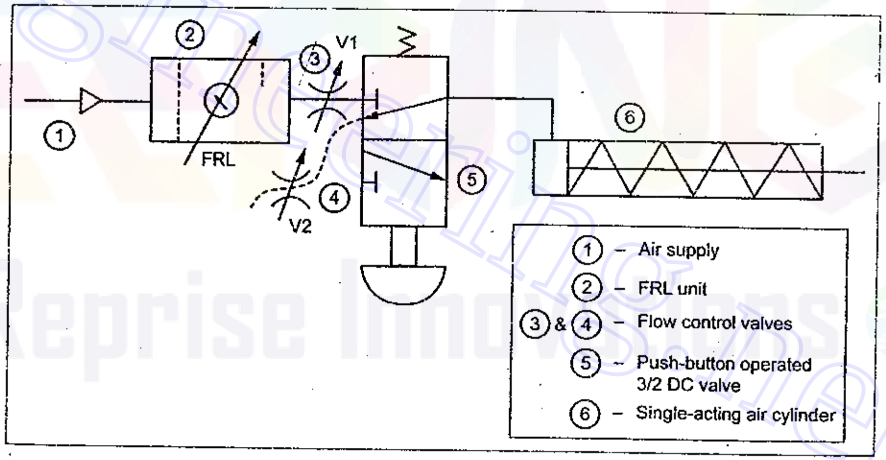

②
③
V1
①
FRL
⑥
④
⑤
V2
① – Air supply
② – FRL unit
③ & ④ – Flow control valves
⑤ – Push-button operated 3/2 DC valve
⑥ – Single-acting air cylinder

Fig. 13.12. Circuit for the control of a single-acting pneumatic cylinder

13.15.2. Operation

Extension : When the push-button is pressed, the 3/2 DC valve is shifted to bottom envelope flow path configuration. So the compressed air flows into the blind end of the cylinder and hence the cylinder extends.

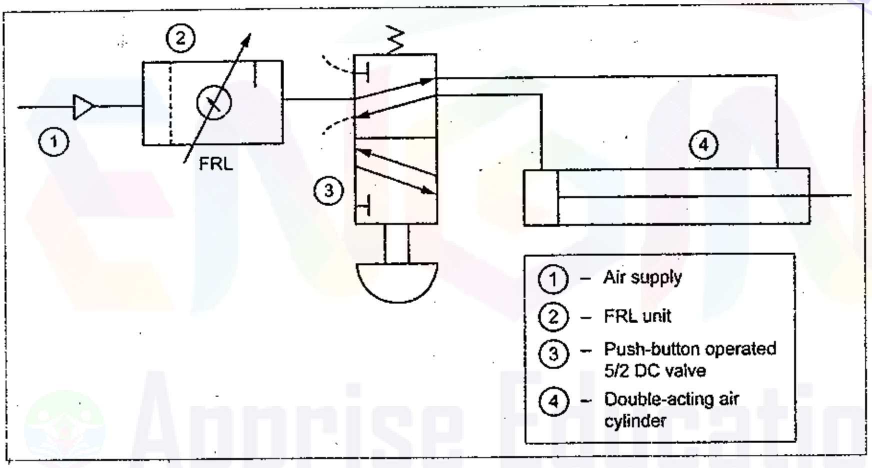
Retraction : When the push-button is released, the 3/2 DC valve is shifted to top envelope flow path configuration. Now the spring located at the rod end of the cylinder retracts the piston to exhaust the air to the atmosphere.

In this circuit, the adjustable flow control valves V1 and V2 are used to control the speed of extension and retraction of the cylinder. It may be noted in the circuit that the short dashed line leading from the exhaust port represents the exhausted air released directly into the atmosphere.

13.16. CONTROL OF A DOUBLE-ACTING PNEUMATIC CYLINDER

13.16.1. Circuit

Fig.13.13 illustrates a circuit that can be used to control a double-acting air cylinder. This circuit has a push-button operated 5/2 DC valve and a double-acting air cylinder.



①
②
FRL
③
④
① – Air supply
② – FRL unit
③ – Push-button operated 5/2 DC valve
④ – Double-acting air cylinder

Fig. 13.13. Circuit for the control of a double-acting pneumatic cylinder

13.16.2. Operation

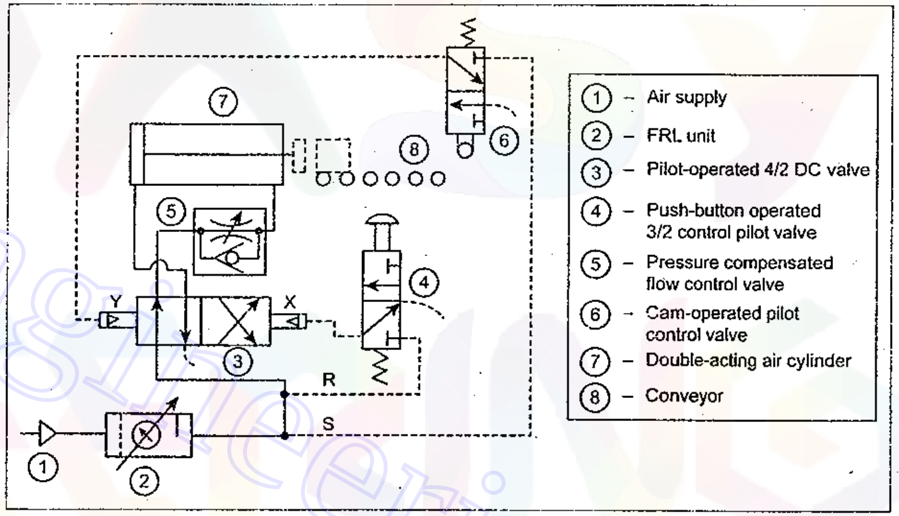
Extension : When the push-button is activated (*i.e.*, pressed), the 5/2 DC valve is shifted to bottom envelope flow path configuration. So the compressed air flows into the blind end of the cylinder and hence the cylinder extends. At the same time, the air at the rod end of the cylinder is exhausted directly to the atmosphere.

Retraction : When the push-button is deactivated (*i.e.*, released), the 5/2 DC valve is shifted to spring-offset mode. Now the compressed air flows into the rod end of the cylinder and hence the cylinder retracts. At the same time, the air at the blind end of the cylinder is exhausted directly to the atmosphere.

13.17. SEMI-AUTOMATIC CONTROL OF A DOUBLE-ACTING PNEUMATIC CYLINDER (Semi-Automatic Material Handling Circuit)

13.17.1. Circuit

Fig.13.14 illustrates a circuit that provides semi-automatic operation by using pressure-operated pilot controls.



⑦
⑧
⑥
⑤
④
Y
X
③
R
S
①
②
① – Air supply
② – FRL unit
③ – Pilot-operated 4/2 DC valve
④ – Push-button operated 3/2 control pilot valve
⑤ – Pressure compensated flow control valve
⑥ – Cam-operated pilot control valve
⑦ – Double-acting air cylinder
⑧ – Conveyor

Fig. 13.14. Semi-automatic control of a double-acting air cylinder

13.17.2. Operation

Extension : When operator momentarily presses the push-button of 3/2 pilot control valve, the compressed air flows through this valve and enters pilot chamber X shifting the 4/2 DC valve to its right envelope flow path configuration. When the 4/2 DC valve is shifted to its right mode, the compressed air flows to blind end of the cylinder and thus the cylinder extends. At the same time, the air at the rod end of the cylinder is exhausted into the atmosphere directly. It may be noted that the piston out speed of the cylinder is controlled by flow control valve.

Retraction : Once the extension stroke of the cylinder completes, the cam-operated pilot control valve is tripped and air flows to pilot chamber Y of 4/2 DC valve shifting its position. When the 4/2 DC valve is shifted to its left mode, the compressed air flows to the rod end of the cylinder and thus the cylinder retracts. At the same time, the air at the blind end of the cylinder is exhausted to the atmosphere.

For the next cycle, again the operator only needs to momentarily press the push-button. Thus in this semi-automatic circuit, once the operator momentarily presses the push-button, the circuit completes its cycle automatically. This circuit may be used as semi-automatic material handling circuit for pushing the large boxes from transfer table onto conveyor, as shown in Fig.13.14.

13.18. AUTOMATIC PNEUMATIC CYLINDER RECIPROCATING SYSTEM (Continuous Reciprocation Circuit) (Automatic Material handling Circuit)

13.18.1. Circuit

Fig.13.15 illustrates a circuit that produces automatic reciprocation of the pneumatic cylinder. This type of automatic circuits have many applications in the material handling field. This circuit uses two cam-operated pilot control valves, a pilot-pressure operated 4/2 DC valve, two flow control valves, and a double-acting air cylinder.

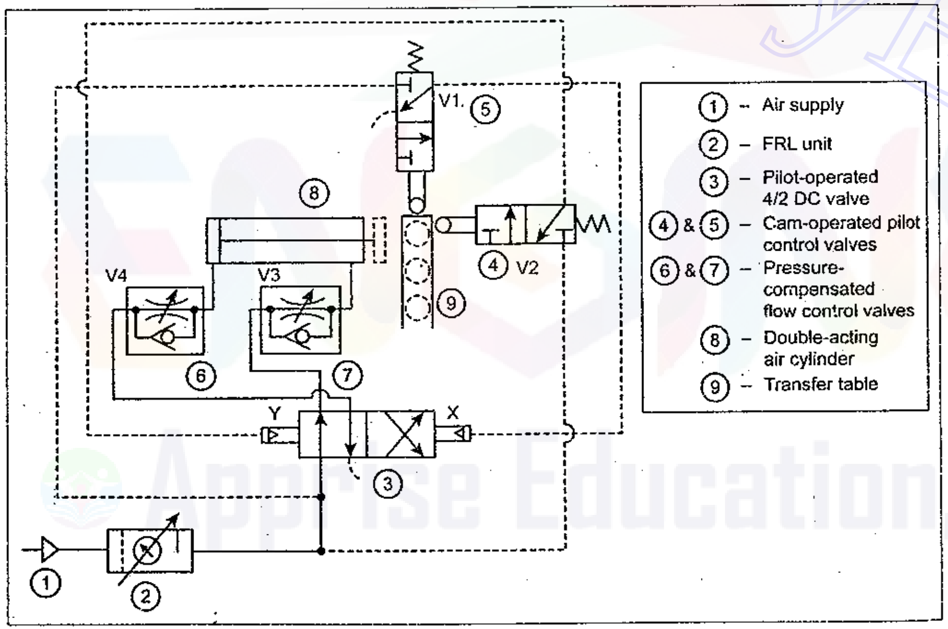

V1. ⑤
⑧
④ V2
V4
V3
⑨
⑥
⑦
Y
X
③
①
②
① – Air supply
② – FRL unit
③ – Pilot-operated 4/2 DC valve
④ & ⑤ – Cam-operated pilot control valves
⑥ & ⑦ – Pressure-compensated flow control valves
⑧ – Double-acting air cylinder
⑨ – Transfer table

Fig. 13.15. Automatic pneumatic cylinder reciprocating system

13.18.2. Operation

Extension : When first workpiece on the transfer table contacts and depresses cam roller of pilot control valve V1, the air flows to pilot chamber X of 4/2 DC valve shifting its position to right mode. When the 4/2 DC valve is shifted to its right envelope flow path configuration, the compressed air flows into the blind end of the cylinder and thus the cylinder extends. The speed of the cylinder is controlled by the flow control valve (V3) through which air is being exhausted from the rod end. Now the workpiece moves from the transfer table onto gravity conveyor.

Retraction : As the piston approaches its end of the cylinder stroke, the cam roller of pilot control valve V2 is depressed and air flows to pilot chamber Y of 4/2 DC valve shifting its position to left mode. When the 4/2 DC valve is shifted to its left envelope flow path configuration, the compressed air flows into the rod end of the cylinder and thus the cylinder extends. Now the speed of the cylinder is controlled by the flow control valve (V4) through which air is being exhausted from the blind end.

Now the second workpiece is fed in and the next cycle automatically starts. Thus the sequence repeats and the cylinder reciprocates continuously without the operator's help.

13.19. PNEUMATIC CYLINDER SEQUENCING CIRCUITS

13.19.1. Sequencing Control of Two Air Cylinders

The circuit illustrating fluidic sequencing control of two pneumatic cylinder will be presented in Section 15.6.2. For more details on this sequencing circuit, refer Chapter 15, Section 15.6.2.

13.19.2. Sequencing of Four Double-Acting Air Cylinders

13.19.2.1. Circuit

Fig.13.16 illustrates a circuit that provides sequencing control of four double-acting pneumatic cylinders. This circuit uses four cam-operated 3/2 pilot control valves, two pilot-operated 4/3 DC valves, and four double-acting air cylinders. These valves are spring-centered so that when rollers ride off the cams, the valves return to neutral position with all ports closed.

13.19.2.2. Operation

First operator engages camshaft drive. As camshaft rotates, cams (1) and (4) depress rollers on 3/2 pilot control valves (1) and (4). From pilot valve (1), air is directed to chamber C of 4/3 DC valve (5). This pilot pressure shifts the position of the 4/3 DC valve (5) to its left mode. When the 4/3 DC valve (5) is shifted to its left envelope flow path configuration, the compressed air flows into blind ends of cylinders (7) and (8), and hence both cylinders (7) and (8) extend. At the same time, air flows through 3/2 pilot control valve (4) to pilot chamber P of 4/3 DC valve (6). This pilot pressure shifts the position of the 4/3 DC valve (6) to its right mode. When the 4/3 DC valve (6) is shifted to its right mode, the air is directed to rod ends of cylinders (9) and (10), and hence both cylinders (9) and (10) retract.

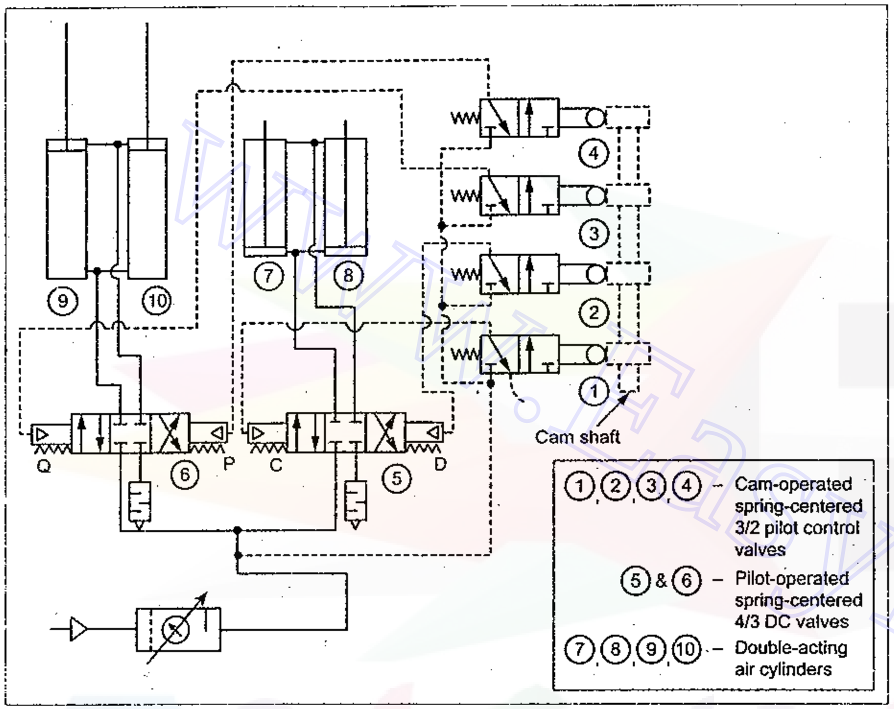

④
③
②
①
Cam shaft
⑦
⑧
⑨
⑩
Q
⑥
P
C
⑤
D
①②③④ – Cam-operated spring-centered 3/2 pilot control valves
⑤ & ⑥ – Pilot-operated spring-centered 4/3 DC valves
⑦⑧⑨⑩ – Double-acting air cylinders

Fig. 13.16. Sequencing of four double-acting air cylinders

As the camshaft rotates 180° angle, cams (1) and (4) release the rollers on 3/2 pilot control valves (1) and (4). Now cams (2) and (3) contact and depress rollers on 3/2 pilot control valves (2) and (3). From pilot valve (2), air is directed to chamber D of 4/3 DC valve (5). This pilot pressure shifts the position of the 4/3 DC valve (5) to its right mode. When the 4/3 DC valve (5) is shifted to its right mode, the compressed air flows into rod ends of cylinders (7) and (8), and hence both cylinders (7) and (8) retract. At the same time air flows through 3/2 pilot control valve (3) to pilot chamber Q of 4/3 DC valve (6). This pilot pressure shifts the position of the 4/3 DC valve (6) to its left mode. When the 4/3 DC valve (6) is shifted to its left mode, the air is directed to blind ends of cylinders (9) and (10), and hence both cylinders (9) and (10) extends.

The cylinder will continue to cycle until the operator disengages the camshaft drive.

13.20. SPEED CONTROL CIRCUITS

13.20.1. Speed Control of a Pneumatic Cylinder

For regulating the speed of pneumatic cylinders, the flow control valves are used. Also similar to the methods discussed under hydraulic circuits, the different speed control methods are (*i*) meter-in circuit, (*ii*) meter-out circuit, and (*iii*) bleed-off circuit.

13.20.2. Meter-in Speed Control of Pneumatic Cylinder

13.20.2.1. Circuit

Fig.13.17 illustrates a meter-in circuit that can be used to control the speed of an air cylinder using a flow control valve.

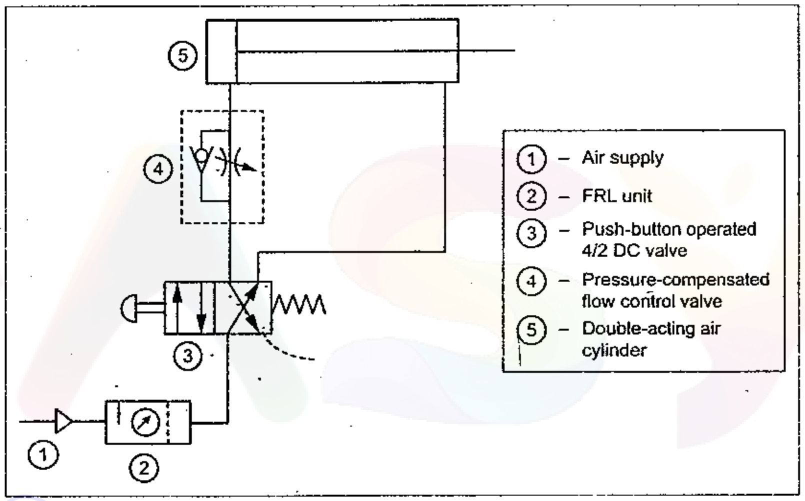

⑤
④
③
①
②
① – Air supply
② – FRL unit
③ – Push-button operated 4/2 DC valve
④ – Pressure-compensated flow control valve
⑤ – Double-acting air cylinder

Fig. 13.17. Meter-in circuit

13.20.2.2. Operation

Extension : When 4/2 DC valve is shifted to its left mode, air flows to the blind end of the cylinder via the flow control valve. This air flow extends the cylinder. Here the extending speed of the cylinder depends on the setting of the flow control valve. Thus the extending speed can be regulated by just regulating the air flow in the flow control valve.

Retraction : When the 4/2 DC valve is shifted to its right mode, air flows to the rod end of the cylinder and hence the cylinder retracts. The air from the blind end of the cylinder is exhausted to the atmosphere through the check valve as well as the flow control valve.

13.20.3. Meter-out Speed Control of Pneumatic Cylinder

13.20.3.1. Circuit

Fig.13.18 illustrates a meter-out circuit to control the speed of an air cylinder.

13.20.3.2. Operation

The operation of meter-out circuit is very much similar to that of the meter-in circuit. The only difference is that meter-out flow control system controls the air flow rate out of the cylinder. In other words, meter-out circuit controls the retracting speed of the air cylinder.

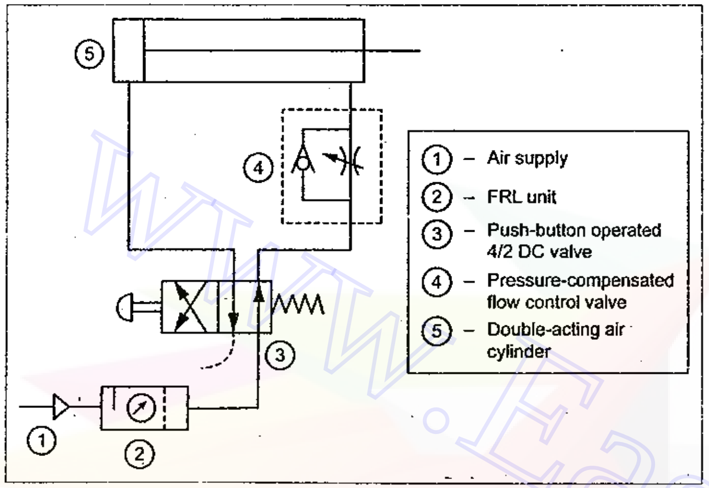

⑤
④
③
①
②
① – Air supply
② – FRL unit
③ – Push-button operated 4/2 DC valve
④ – Pressure-compensated flow control valve
⑤ – Double-acting air cylinder

Fig. 13.18. Meter-out circuit

13.20.4. Speed Control of Double-Acting Pneumatic Cylinder with Two Flow Control Valves

13.20.4.1. Circuit

Fig.13.19 illustrates a speed control circuit of double-acting air cylinders using two flow control valves.

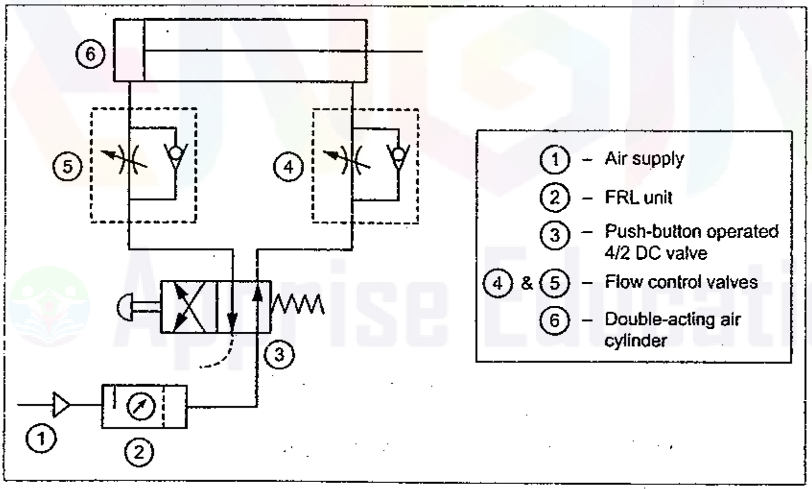

⑥
⑤
④
③
①
②
① – Air supply
② – FRL unit
③ – Push-button operated 4/2 DC valve
④ & ⑤ – Flow control valves
⑥ – Double-acting air cylinder

Fig. 13.19. Speed control with two flow control valves

13.20.4.2. Operation

In this circuit, the two flow control valves—one at the inlet line and other at the outlet line of the pneumatic cylinder—are used to regulate the speed of both the extending and retracting motion of the cylinder.

13.21. ACTUATION OF PNEUMATIC MOTOR

13.21.1. Circuit

Fig.13.20 illustrates a circuit to control unidirectional pneumatic motor.

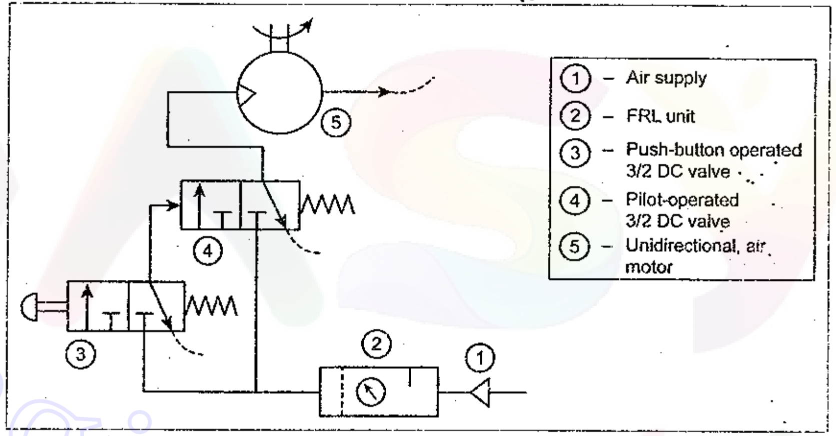

⑤
④
③
②
①
① – Air supply
② – FRL unit
③ – Push-button operated 3/2 DC valve
④ – Pilot-operated 3/2 DC valve
⑤ – Unidirectional, air motor

Fig. 13.20. Pneumatic motor circuit

13.21.2. Operation

When the push-button operated 3/2 DC valve is shifted to its left mode, the air-operated 3/2 DC valve is actuated in its left envelope flow path configuration. Now the air flows to the inlet port of the air motor and hence the motor rotates.

When the push-button operated 3/2 DC valve is shifted to its right mode, the air gets exhausted in the valve and hence the motor rotation will be stopped.

HYDROPNEUMATIC CIRCUITS

13.22. HYDROPNEUMATIC (OR PNEUMOHYDRAULIC) CIRCUITS

13.22.1. What are Hydropneumatic Circuits ?

✓ In some applications, the hydraulic and pneumatic circuits are coupled to get best use of the advantages of both oil and air mediums. This combination circuits are known as ***hydropneumatic*** or ***pneumohyraulic circuits.***

✓ As we know, due to compressibility characteristics of air, the pneumatic actuators are not preferred for precision control of position and speed. At the same time, hydraulic systems are not so economical as well as lacks overall fastness when compared to pneumatic systems. The combination of hydraulics and pneumatics solves the above problems of precision control, fastness and economy.

✓ However, it should be kept in mind that though both fluids (oil and air) are used in the same circuit, they are not mixed together. In fact, every precaution should be taken to keep them separated.

13.22.2. Uses of Hydropneumatic Circuits

1. Using the combination of air-hydraulic unit, the quick action of air and smooth, high-pressure action of oil can be blended.
2. The combination circuit will reduce space requirements.
3. The combination circuit will reduce initial and maintenance cost of original equipment.
4. It will increase the performance of the equipment.
5. It will allow more flexibility.
6. The combination circuit such as an air-hydraulic cylinder is especially suitable in explosive atmospheres because of the absence of electrical equipment.

Now we shall discuss two such combination circuits.

13.23. AIR-OVER-OIL CIRCUIT

13.23.1. Circuit

Fig.13.21 illustrates a typical air-over-oil circuit to make best use of advantages of both fluid mediums for counterbalancing application. This circuit uses an air-oil surge tank, a manually operated 3/3 DC valve, a FRL unit, a flow control valve, a pressure relief valve, and a cylinder. In the surge tank, oil is filled at the bottom and the air at the top.

13.23.2. Operation

Extension : When the 3/3 DC valve is shifted to its upper envelope flow path configuration, the compressed air flows via FRL unit and the valve to the surge tank. So the surge tank is pressurized by the compressed air. This pushes the oil (out of the bottom of the surge tank) to the blind end of the cylinder through the flow control valve. Thus the cylinder extends to lift a load. Here the flow control valve can be used to regulate the extension speed of the cylinder.

Retraction : When the 3/3 DC valve is shifted to its lower envelope flow path configuration, the air leaves the surge tank and exhausts into the atmosphere via the DC valve. So the oil at the blind end of the cylinder returns back steadily through the flow control valve and thus the cylinder retracts.

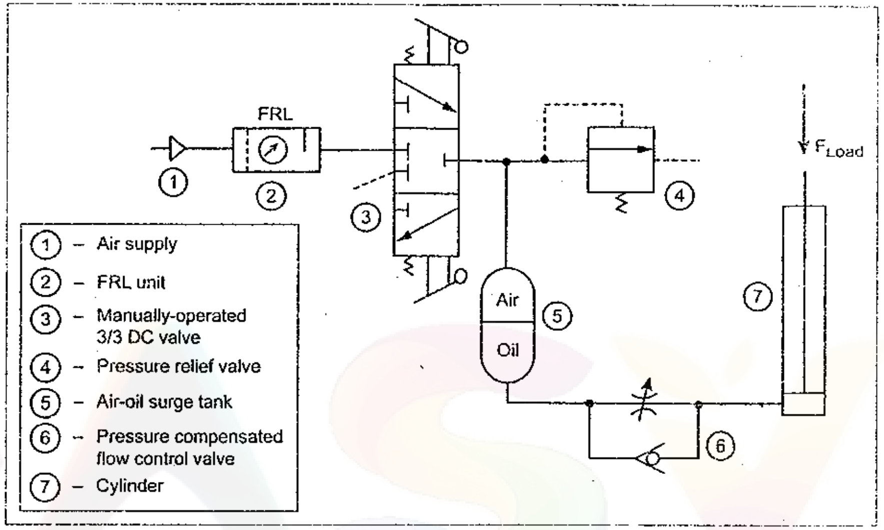

FRL
F_Load
Air
Oil
① – Air supply
② – FRL unit
③ – Manually-operated 3/3 DC valve
④ – Pressure relief valve
⑤ – Air-oil surge tank
⑥ – Pressure compensated flow control valve
⑦ – Cylinder
①
②
③
④
⑤
⑥
⑦

Fig. 13.21. Air-over-oil circuit

The load (F_{load}) can be stopped at any intermediated position by shifting the 3/3 DC valve to its spring-centered position. This circuit eliminates the use of a costly hydraulic pump and an oil reservoir. Also this circuit uses the oil for the advantage of generating high force and precision control of the cylinder.

13.24. AIR-OVER-OIL INTENSIFIER CIRCUIT

The air-over-oil intensifier circuit can be used for driving a cylinder over a large distance at low pressure and then over a small distance at high pressure (such as in punch press applications). This circuit have been discussed already in Section 8.14.2. For more details, refer Chapter 8, Section 8.14.2.

13.25. COMPARISON OF HYDRAULICS, PNEUMATICS, AND HYDROPNEUMATICS

Table 13.1 presents the comparison between the hydraulic, pneumatic and hydro-pneumatic systems.

Table 13.1. Comparison of hydraulics, pneumatics, and hydropneumatics

Sl.No.	Parameter	Hydraulics	Pneumatics	Hydropneumatics
1.	Speed of actuator	Limited	Very high speed is possible	High speed is possible
2.	Control of actuator	Very precise stroke control is possible	Precise control not possible (due to compressibility of air)	Better control of actuator

Sl.No.	Parameter	Hydraulics	Pneumatics	Hydropneumatics
3.	Suitability for feed movement in machine tool applications	Highly suitable	Not suitable	Suitable
4.	Resistance against fluctuating loads	High	Very low	Medium
5.	Operating pressure	Low to very high	Low	Low to medium
6.	Operating fluid	Only oil	Only air	Both oil and air
7.	Weight-to-pressure ratio	Small	Large	Large
8.	System rigidity	Good	Poor	Good
9.	Necessity of pump	Necessary	Not necessary	Need does not arise
10.	Problem of cavitation	Cavitation is a major problem	No such problem	No cavitation problem, but there is a possibility of air and oil mixing
11.	Operating cost	Moderate	Very low	Low

PNEUMATIC LOGIC CIRCUITS

13.26. DESIGN OF PNEUMATIC LOGIC CIRCUITS

In the preceding sections, we have discussed few basic pneumatic circuits. It should be noted that a pneumatic circuit for a particular application can be designed in various methods. The five methods commonly used by engineers are :

1. Cascade method,
2. Classic or intuitive method,
3. Step-counter method,
4. Karnaugh-Veitch (K-V) mapping method, and
5. Combinational circuit design.

However, the design of pneumatic logic circuits using cascade method is more important from our subject point of view.

13.26.1. Cascade Method of Pneumatic Circuit Design

The cascade method is found to be the simplest and easiest method of designing pneumatic logic circuits.

13.26.1.1. Procedure

The following step by step procedure may be followed while using the cascade method.

Step1 : Each cylinders are given, for convenience, individual letters (say A, B, C, *etc.*). The given sequence is written first with '+' representing extension (forward) stroke of the cylinder and '–' representing retraction (return) stroke of the cylinder. (For example A^+, B^+, A^-, B^-, *etc.*)

Step 2 : The given sequence is split into minimum number of groups. The grouping can be done as below :

(*i*) The first group is split where the change in stroke occurs.

(*ii*) The second, third and subsequent groups are formed such that maximum of one change occurs within the group.

(*iii*) No letter should be repeated within any group.

(*iv*) The groups are identified by letters like I, II, III, *etc.*

Illustration : Let us assume the sequence A^+ B^+ B^- C^+ C^- A^-. This sequence can be splitted into three groups as shown below :

$$\underset{I}{\underline{A^+B^+}},\ \underset{II}{\underline{B^-C^+}},\ \underset{III}{\underline{C^-A^-}}$$

Step 3 : Each group is assigned a pressure manifold line which must be pressurised only during the time the particular group is active.

∴ *Number of pressure lines = Number of groups*

Step 4 : Selection of valves :

(*i*) Each cylinder is provided with a pilot operated 4/2 DC valve.

∴ *Number of pilot control valves = Number of cylinders*

(*ii*) Limit valves are positioned at either end actuated by the piston rod to identify the extension and retraction of cylinders. The limit valves are denoted by a_0, a_1, b_0, b_1, *etc.*, where the suffix '0' corresponds to valves which are actuated at the end of return stroke and the suffix '1' corresponds to valves which are actuated at the end of forward stroke. Each cylinder requires two limit valves.

∴ *Number of limit valves = 2 × Number of cylinders*

Each manifold line supplies air pressure to those limit valves within its particular group.

(*iii*) In order to pressurize the various manifold lines in the proper order, one or more group changing valves or cascade valves are used.

∴ *Number of cascade (or group changing) valves = Number of groups – 1*

Step 5 : The valve connections are made as follows :

(*i*) The output of each limit valve is connected to the pilot input corresponding to the next sequence step.

(*ii*) The limit valve corresponding to the last step of the given group is 'not' connected to the pilot actuation of the DC valve of next cylinder. Instead, it is connected to the pilot line of the group changing or cascade valve so as to pressurize the manifold of the subsequent group.

This manifold line is then connected to the pilot line corresponding to the first step of the next group.

13.26.2. Advantages of Cascade Method

1. Circuit design, drawing and checking can be accomplished very quickly.
2. Fault diagnosis and trouble-shooting are very simple.
3. Required task by each cylinder and their signal elements is fully ensured.
4. This avoids a problem that may occur because of air becoming trapped in the pressure line to control a valve and so preventing the valve from switching.

Example 13.2 *Three pneumatic cylinders A, B, and C are used in an automatic sequence of operation. A cylinder extends, B cylinder extends, B cylinder retracts and then A cylinder retracts, C cylinder extends and C cylinder retracts. Develop pneumatic circuits by cascade method.*

☺ ***Solution :*** The steps involving during the design of this circuit is explained as below :

Step 1 : Given sequence is $A^+ B^+ B^- A^- C^+ C^-$

Step 2 : The given sequence can be initially splitted into three groups as

$$\underset{\text{I}}{\underline{A^+ B^+}}, \quad \underset{\text{II}}{\underline{B^- A^- C^+}}, \quad \underset{\text{III}}{\underline{C^-}}$$

In order to keep the number of groups minimal, the C^- can be assigned to group I. So the ideal grouping is as follows :

$$\underset{\text{I}}{\underline{C^- A^+ B^+}}, \quad \underset{\text{II}}{\underline{B^- A^- C^+}}$$

Step 3 : Number of pressure lines = Number of groups = 2

Step 4 : Selection of valves :

(*i*) Number of pilot operated 4/2 DC valve = Number of cylinders = 3

Thus three cylinder actuation—VA, VB, VC—are provided.

(*ii*) Number of limit valves = 2 × Number of cylinders = 2 × 3 = 6

Thus six limit valves—a_0, a_1, b_0, b_1, c_0, c_1—are provided.

(*iii*) Number of cascade (or group changing) valves $= \left\{ \begin{matrix} \text{Number of} \\ \text{groups} \end{matrix} \right\} - 1 = 2 - 1 = 1.$

So for this circuit, only one cascade valve is sufficient.

Step 5 : The valve connections are made as follows :

(*i*) The cascade valve CV is shifted to its left envelop flow path configuration so that the pressure manifold to group I is pressurized. First line I is connected directly to the pilot line (–) of 4/2 DC valve VC. So retraction of C (C^-) starts when group I is pressurized.

At the end of retraction of C, the limit valve c_0 is actuated. Now the pressure from manifold line I passes through c_0 to the pilot line (+) of 4/2 DC vale VA. As a result, cylinder A extends (A^+) and actuates limit valve a_1. Pressure then passes from manifold line I through a_1 to the pilot line (+) of 4/2 DC valve VB; this causes cylinder B to extend (B^+) and actuates limit valve b_1. Thus the sequencing of Group I is completed.

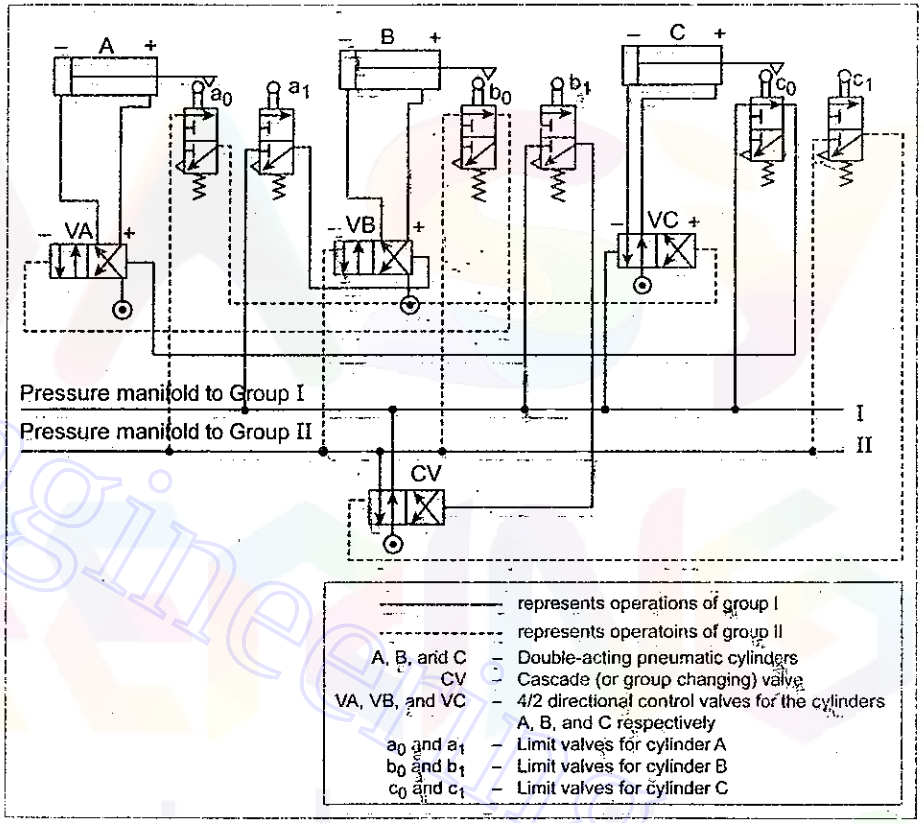

– A +
– B +
– C +
a0
a1
b0
b1
c0
c1
– VA +
– VB +
– VC +
CV
Pressure manifold to Group I
Pressure manifold to Group II
I
II
represents operations of group I
represents operatoins of group II
A, B, and C – Double-acting pneumatic cylinders
CV – Cascade (or group changing) valve
VA, VB, and VC – 4/2 directional control valves for the cylinders A, B, and C respectively
a0 and a1 – Limit valves for cylinder A
b0 and b1 – Limit valves for cylinder B
c0 and c1 – Limit valves for cylinder C

Fig. 13.22. Cascade circuit for $C^-A^+B^+B^-A^-C^+$ *sequence*

(*ii*) ***Pressure manifold :*** Now the pressure line should be shifted from Group I to Group II. The pressure from limit valve b_1 shifts the cascade valve CV to its right envelope flow path configuration and thus the pressure manifold II is pressurised. Line II is connected directly to the pilot line (–) of 4/2 DC valve VB. So retraction of B (B^-) starts when a group II is pressurized.

At the end of retraction of B, the limit valve b_0 is actuated. Now the pressure from manifold line II pass through limit valve b_0 to the pilot line (–) of 4/2 DC valve VA.

As a result, cylinder A retracts (A⁻) and actuates limit valve a_0. Pressure then passes from manifold line II through limit valve a_0 to the pilot line (+) of 4/2 DC valve VC; this causes cylinder C to extend (C⁺) and actuates limit valve c_1.

(*iii*) Now the pressure from limit valve c_1 shifts the cascade valve CV to its left envelop flow path configuration and thus the pressure manifold I is pressurised again. Thus the automating sequencing of C⁻A⁺B⁺B⁻A⁻C⁺ can be achieved.

The cascade circuit for the above $A^+B^+B^-A^-C^+C^-$ sequencing is drawn as shown in Fig.13.22.

Example 13.3 ***Develop an electropneumatic circuit by cascade method for the following sequence : $A^+B^+B^-A^-$ where A and B stand for cylinders, (+) indicates extension and (–) retraction of cylinders.***

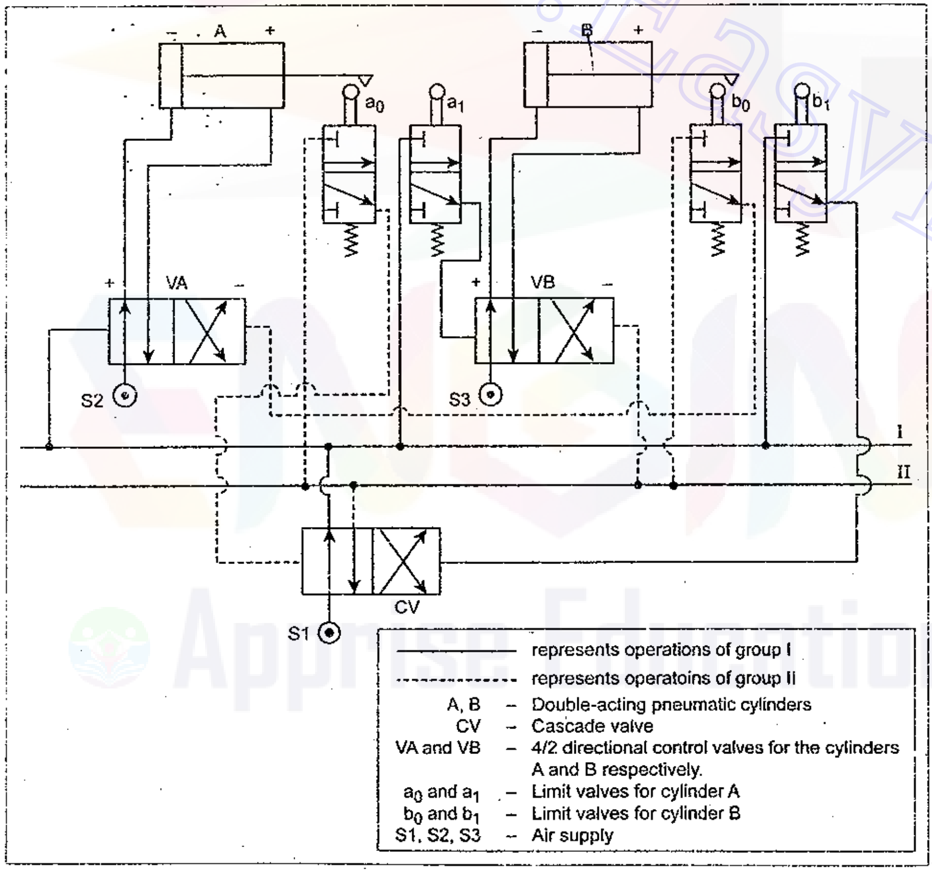

A
–
+
B
–
+
a_0
a_1
b_0
b_1
+
VA
–
+
VB
–
S2
S3
I
II
CV
S1
———— represents operations of group I
- - - - - represents operatoins of group II
A, B – Double-acting pneumatic cylinders
CV – Cascade valve
VA and VB – 4/2 directional control valves for the cylinders A and B respectively.
a_0 and a_1 – Limit valves for cylinder A
b_0 and b_1 – Limit valves for cylinder B
S1, S2, S3 – Air supply

Fig. 13.23. Cascade circuit for $A^+ B^+ B^- A^-$ sequence

☺ ***Solution :*** The solution to this design problem is very much similar to that of the previous problem. So the same procedure may also be followed for this problem.

Step 1 : Given sequence : $A^+ B^+ B^- A^-$

Step 2 : Grouping : $\underset{\text{I}}{\underline{A^+ B^+}}, \underset{\text{II}}{\underline{B^- A^-}}$

Step 3 : Number of pressure lines = Number of groups = 2

Step 4 : (*i*) Number of pilot operated 4/2 DC valve = Number of cylinders = 2

(*ii*) Number of limit valves = 2 × Number of cylinders = 2 × 2 = 4

(*iii*) Number of cascade valves = Number of groups – 1 = 2 – 1 = 1

Step 5 : The cascade circuit and their valve connections for the sequence $A^+ B^+ B^- A^-$ is drawn as shown in Fig.13.23.

Example 13.4 ***Design and explain the fluid power circuit for a drilling machine to discuss the following functions :***

(i) Clamping the workpiece, (ii) Drilling the workpiece, and (iii) Unclamping the workpiece.

☺ ***Solution :*** Let us use two cylinders A and B for clamping and drilling operations respectively. The operation sequence is as follows :

Cylinder A extends to clamp the workpiece (A+).

Cylinder B extends to do the drilling (B⁺).

Cylinder B retracts after drilling (B⁻).

Cylinder A retracts after to unclamp the workpiece (A⁻). So the sequence is $A^+ B^+ B^- A^-$. Now the solution to this sequence is exactly the same as that of previous problem. See Fig.13.23 for the required circuit.

Example 13.5 ***Design an electropneumatic circuit by cascade method for the following punching press application :***

Cylinder A is used to clamp the workpiece; Cylinder B is used for punching; and cylinder C removes the workpiece from the station.

☺ ***Solution :*** For the given problem, the operation sequence can be written as below :

Cylinder A extends to clamp the workpiece (A⁺).

Cylinder B extends to do the punching (B⁺).

Cylinder B retracts after punching (B⁻).

Cylinder A retracts to unclamp the workpiece (A⁻).

Cylinder C extends to remove the workpiece (C+).

Cylinder C retracts after removal of workpiece (C⁻).

Thus the sequence for this case is $A^+ B^+ B^- A^- C^+ C^-$. Now the solution to this sequence is exactly the same as that of Example 13.2. Fig.13.22 for the required circuit.

Example 13.6 ***Design an electropneumatic circuit using cascade method for the following sequence $A^+ B^+ B^- C^- C^+ A^-$, where A, B and C stand for cylinders, (+) indicates extension and (–) retraction of cylinders.***

☺ ***Solution :***

Step I : Given sequence : $A^+ B^+ B^- C^- C^+ A^-$

Step II : Grouping : $\dfrac{A^+ B^+}{I}, \dfrac{B^- C^-}{II}, \dfrac{C^+ A^-}{III}$

Step III : Number of pressure lines = Number of groups = 3

Step IV : (*i*) Number of pilot operated 4/2 DC valve = Number of cylinders = 3

(*ii*) Number of limit valves = 2 × Number of cylinders = 2 × 3 = 6

(*iii*) Number of cascade valves = Number of groups – 1 = 3 – 1 = 2

Step V : The cascade circuit and their valve connections for the sequence $A^+ B^+ B^- C^- C^+ A^-$ is drawn as shown in Fig.13.24.

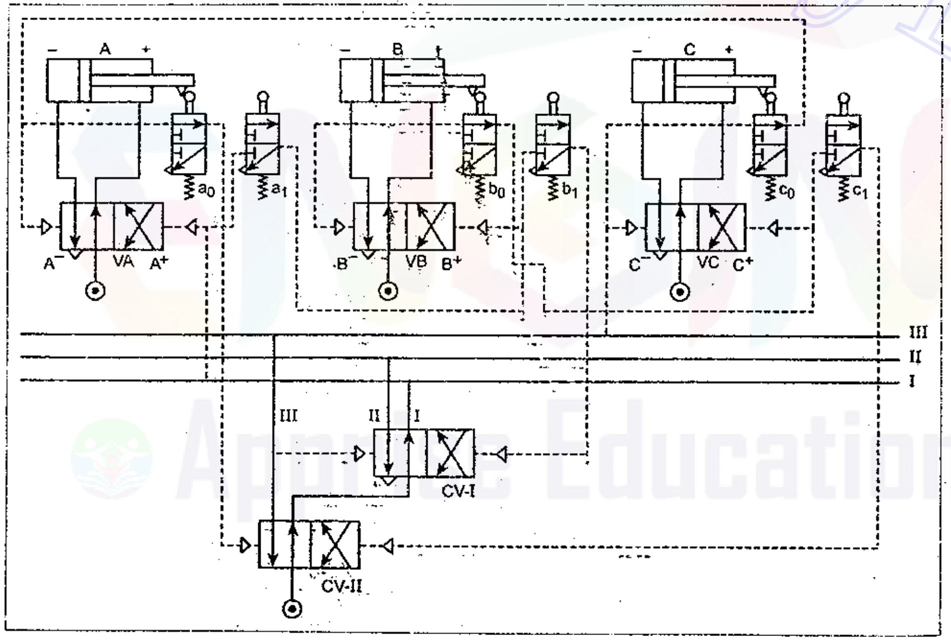


Fig. 13.24. Cascade circuit for $A^+ B^+ B^- C^- C^+ A^-$ sequence

REVIEW AND SUMMARY

✓ *In this chapter, variety of hydraulic, pneumatic, and pneumohydraulic circuits have been designed for various applications.*

✓ *The four important factors that should be considered while designing any fluid power circuit are :*

(*i*) *Safety of operation,*
(*ii*) *Performance of desired function,*
(*iii*) *Efficiency of operation, and*
(*iv*) *Cost.*

✓ ***A hydraulic circuit*** *is the graphic representation of the hydraulic components in a hydraulically operated machine.*

✓ *In this chapter, the design, operation, and purpose of the following hydraulic circuits have been discussed :*

(*i*) *Control of a single-acting hydraulic cylinder,*
(*ii*) *Control of a double-acting hydraulic cylinder,*
(*iii*) *Regenerative circuit,*
(*iv*) *Hydraulic circuit for machine tool applications,*
(*v*) *Pressure intensifier circuit in punching press application,*
(*vi*) *Sequencing of two double-acting cylinders,*
(*vii*) *Automatic cylinder reciprocating system,*
(*viii*) *Synchronizing hydraulic cylinders connected in series,*
(*ix*) *Speed control of a hydraulic cylinder,*
(*x*) *Speed control of a hydraulic motor, and*
(*xi*) *Two-handed safety circuit.*

✓ ***A regenerative circuit*** *is used to speed up the extending speed of the double-acting cylinder.*

✓ ***In meter-in-speed (or flow) control circuit,*** *the flow control valve is located in the line leading to the inlet port of the cylinder.*

✓ ***In meter-out speed (or flow) control circuit,*** *the flow control valve is located in the outlet line of the hydraulic cylinder.*

✓ ***Fail-safe circuits*** *are designed to safe-guard the operator, the machine, and the workpiece.*

✓ ***A pneumatic circuit*** *is defined as the graphic representation of the pneumatic components in a pneumatically operated machine.*

- ✓ *In this chapter, the design, operation, and purpose of the following pneumatic circuits have been presented :*
  - *(i) Control of a single-acting pneumatic cylinder,*
  - *(ii) Control of a double-acting pneumatic cylinder,*
  - *(iii) Semi-automatic control of a double-acting pneumatic cylinder,*
  - *(iv) Automatic pneumatic cylinder reciprocating system,*
  - *(v) Sequencing control of two air cylinders,*
  - *(vi) Sequencing of four double-acting air cylinders,*
  - *(vii) Speed control of a pneumatic cylinder, and*
  - *(viii) Actuation of pneumatic motor.*
- ✓ *In some applications, the hydraulic and pneumatic circuits are coupled to get best use of the advantages of both oil and air mediums. This combination circuit is known as* ***hydropneumatic or pneumohydraulic circuits.***
- ✓ *At the end of this chapter, the design, operation, and purpose of the following two* ***hydropneumatic circuits*** *have been explained :*
  - *(i) Air-over-oil circuit, and*
  - *(ii) Air-over-oil intensifier circuit.*

KEY TERMS ONE SHOULD REMEMBER

Fluid power circuits
Hydraulic circuits
Pneumatic circuits
Hydropneumatic circuits
Pneumohydraulic circuits
Regenerative circuits
Sequencing circuits
Pressure intensifier circuit
Continuous reciprocation circuit
Synchronizing circuits
Speed control circuits
  Meter-in circuit
  Meter-out circuit
  Bleed-off circuit
Flow control circuits
Fail-safe circuits
Semi-automatic material handling circuit
Automatic material handling circuit
Air-over-oil circuit
Air-over-oil intensifier circuit

REVIEW QUESTIONS

Short Answer Type Questions

1. What are the important factors that should be considered while designing a fluid power circuit ?
2. Name any four essential components required for a hydraulic circuit design.

3. What is meant by hydraulic power pack ?
4. What is the use of a regenerative circuit ?
5. Why is the load-carrying capacity of a regenerative cylinder large when its piston rod area is large ?
6. Why is extension stroke faster than retraction stroke in a regenerative circuit ?
7. What do you mean by sequencing of cylinders ? Name some applications where it would be desirable to have sequencing of two cylinders.
8. What do you mean by synchronization of cylinders ? Name some applications where it would be desirable to have two cylinders synchronized in movement.
9. Name the various methods by which synchronization of cylinders can be achieved.
10. Name the three ways of applying flow control valves in a fluid power circuit.
11. Differentiate between meter-in and meter-out circuits with respect to speed control circuits.
12. What do you mean by bleed-off circuit control ?
13. What is the purpose of a fail-safe circuit ?
14. In what ways, pneumatic circuits differ from the hydraulic circuits ?
15. What are hydropneumatic circuits ?
16. List any four advantages of using pneumohydraulic circuits.
17. What is meant by an air-over-oil system ?

Essay Answer Type Questions

1. Explain with suitable circuits how the single-acting and double-acting hydraulic cylinders are controlled.
2. Explain a regenerative circuit with a suitable application.
3. Draw and explain a hydraulic circuit diagram of a hydraulic system having a double-acting cylinder which has a rapid approach speed, then a slow feed motion and at the end of the stroke the cylinder returns quickly.
4. Show diagrammatically a fluid power circuit suitable for hydraulic shaper drive. The following provisions should be made in your circuit design :
   (*i*) Quick return motion;
   (*ii*) Setting of stroke length; and
   (*iii*) Variable cutting speed by choice.
5. Draw a hydraulic circuit for the operation of a hydraulic press and explain.
6. Design and explain the hydraulic power circuit for sequencing of the following operations in a drilling machine :
   (*i*) Clamping the workpiece,
   (*ii*) Drilling the workpiece.
   (*iii*) Unclamping the workpiece.

7. Draw a single cylinder, continuous reciprocation circuit using suitable components and briefly explain.
8. With a neat circuit, explain how two hydraulic cylinders' motion can be synchronized.
9. Explain with the help of a hydraulic circuit, how the cylinder speed can be controlled by metering-out oil from the cylinder.
10. What is a fail-safe circuit ? With suitable diagram, explain two-handed safety circuit.
11. Explain with suitable circuits, how the single-acting and double-acting pneumatic cylinders can be controlled.
12. With a neat diagram explain the semi-automatic material handling pneumatic circuit.
13. Draw a pneumatic circuit for automatic to and fro operation of a double-acting cylinder.
14. Explain the sequencing of four double-acting air cylinders with a neat circuit.
15. Explain with the help of a pneumatic circuit, how the cylinder speed can be controlled by metering-in air to the cylinder.
16. (*a*) With the help of a diagram explain the air-over-oil circuit.
    (*b*) Compare and contrast between hydraulic, pneumatic, and hydropneumatic circuits.

□□

Unit 5

Design of Pneumatic Circuits

Chapter 14 : Servo Systems and Proportional Controls

Chapter 15 : Logic Controls in Fluid Power Systems

Chapter 16 : Fluid Power Circuits: Failure and Troubleshooting

Apprise Education, Reprise Innovations

Chapter 14

Servo Systems and Proportional Controls

"To dare is to lose one's footing momentarily. To not dare is to lose oneself."

—Soren Kierkegoard

"We can discover this meaning in life in three different ways: (1) by doing a deed; (2) by experiencing a valve; and (3) by suffering."

—Victor Frankl

"Nothing great was ever achieved without enthusiasm."

—Emerson

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Understand the importance of servo systems and proportional controls in fluid power systems.

☑ Identify and explain the elements of a basic closed-loop servo system.

☑ Describe the purpose, construction, and operation of various types of servo valves such as hydromechanical and electrohydraulic servo valves.

☑ Discuss the purpose, construction, and operation of various types of proportional valves such as proportional pressure relief valve, proportional pressure reducing valve, and proportional direction control valve.

CHAPTER

14

SERVO SYSTEMS AND PROPORTIONAL CONTROLS

14.1. INTRODUCTION

In the fluid power systems, especially in hydraulic systems, fluid power designers and engineers are continuously trying to provide accurate positioning of the load with improved control on speed, force, and other parameters. In this regard, there has been tremendous development in the field of control technology. Among them, servo and proportional controls are being increasingly used in various fluid power applications. These servo and proportional controls can be found in various fields like production, material handling, aviation, shipping, robotics, *etc*. Also in the automatic control of many machine functions, there are requirements such as the exceptionally high degree of accuracy in acceleration, velocity, and positioning. These requirements can be met by servo control systems.

In this chapter, we shall discuss the purpose, construction, and operations of various servo and proportional control systems.

SERVO SYSTEMS

14.2. SERVO SYSTEMS

14.2.1. What is a Servo System ?

- ✓ In general, a system in which a small input force is capable to control a larger output force is called as a servo system.
- ✓ ***Definition :*** *A servo control systems is one in which a comparatively large amount of power is controlled by small impulses or command signals and any errors are corrected by feedback signals.*
- ✓ As stated in the above definition, a servo system should provide both signal amplification and automatic correction of any deviation that may take place between the output quantity and quantity set by the command signal.
- ✓ Basically most of the servo systems are closed-loop systems.

14.2.2. Elements of a Basic Closed-Loop Servo System

Fig.14.1 shows a block diagram of a basic closed-loop servo circuit.

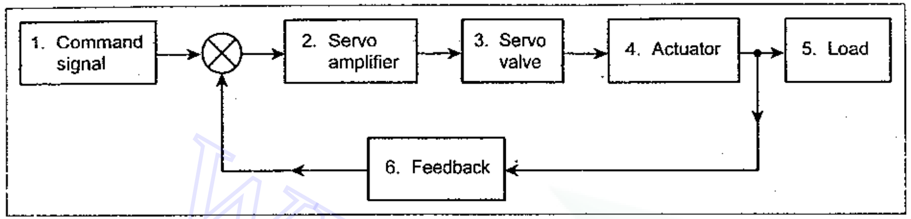


Fig. 14.1. A block diagram of a basic closed-loop servo circuit

As shown in Fig.14.1, a closed-loop servo system consists of following six elements :

1. Command signal : The command signal may be derived from a punched card, a tape, a tachometer, a potentiometer, or some other device.

2. Servo amplifier : The servo amplifier receives a low-power input signal and amplifies it to a higher power level.

3. Servo valve : The servo valve receives the output signal from the amplifier to actuate the servo valve torque motor.

4. Actuator : The actuator could be linear (hydraulic/pneumatic cylinder) or rotary (hydraulic/air motor).

5. Load

6. Feedback transducer : The feedback transducer can be a linear variable differential transformer (LVDT), a tachometer, a potentiometer, or a synchro. This device measures the results at the load and sends a feedback signal to the amplifier unit. The feedback signal is compared with the command signal. If there exists a difference (also called 'error'), a hydraulic/pneumatic correction is automatically made that will bring the output signal into correspondence with the input.

The difference between the output signal and the command signal is called the ***'error signal'***. When the error signal is zero, the ideal condition exists. The purpose of the servo system is to bring the error signal to zero.

14.2.3. Servomechanism

A system having a servo valve, servo amplifier and actuator connected together providing a closed loop feedback is known as a servomechanism.

14.3. SERVO VALVES AND SERVO SYSTEMS

14.3.1. What are Servo Valves ?

- ✓ All the valves described in Chapters 7 and 12 are finite position valves. That means, these valves are built around combinations of basic open and shut valves. So whenever the position of a cylinder or the speed of a motor is to be controlled very accurately, an infinite position valve is required.

- ✓ *A servo valve is nothing but a DC valve having infinitely variable positioning capability.* In other words, servo valve is an infinite position valve.
- ✓ The servo valves are used to control not only the direction of fluid flow, but also the amount of flow. When servo valves are coupled with feedback devices, they can be used to control the position, velocity, and acceleration of the actuator accurately.

14.3.2. Types of Servo Valves

The important types of servo valves are given below :

1. Mechanical-type servo valve, and
2. Electrohydraulic servo valve.
   - (*i*) Single-stage servo valve,
   - (*ii*) Two-stage servo valve,
   - (*iii*) Jet pipe servo valve, and
   - (*iv*) Flapper jet servo valve.

14.4. MECHANICAL-TYPE SERVO VALVE (Hydromechanical Servo Valve)

This type of servo valves is generally used for positioning control.

14.4.1. Construction

The construction and operation of a typical mechanical-type servo valve is illustrated in Fig.14.2. The shape of the porting in the sleeve may be square, rectangular, round, or full annulus.

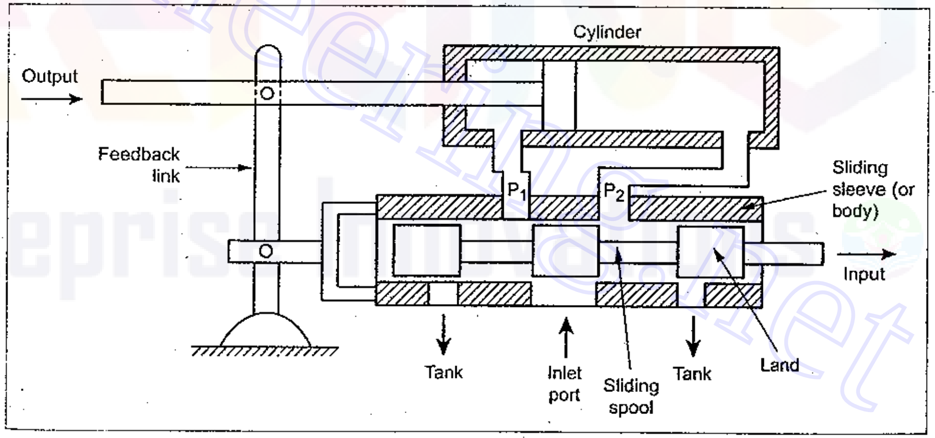


Fig. 14.2. Hydromechanical servo valve

14.4.2. Operation

First a small input force is applied to the spool. This shifts the spool towards right to a position which allows the oil to enter through port P_1 from inlet port. Now the oil flows into the hydraulic cylinder and thus the cylinder retracts towards right.

Since the feedback link is connected with the piston rod and the sliding sleeve as shown in Fig.14.2, the feedback link shifts the sliding sleeve towards right until it blocks off the flow to the hydraulic cylinder through P_1. Thus the given input motion has produced a specific and controlled amount of output motion and also the output motion is fedback to modify the input via the feedback line.

14.4.3. Different 'Lap' Conditions

As for the axial alignment between the lands on the spool and the porting in the sleeve or body, different 'lap' conditions are employed. ***Lap is the length relationship between the metering lands of the spool and the port openings in the sleeve or body.***

(i) Closed centre servo valve : It has an overlapped condition. In this, the lands are slightly longer than the porting area and create a dead zone. But a dead zone is not desirable in a servo valve as it makes the valve unresponsive to small signals.

(ii) Open centre servo valve : It has an underlap condition in that the lands on the spool are somewhat narrower than the port holes in the sleeve. In the center position of the spool, there is a constant fluid flow from the pressure inlet, across the spool to the tank port. Pressure drop due to such restrictions causes an intermediate pressure at the cylinder ports.

(iii) Zero lap servo valve : It is the most desirable construction. This 'zero lap' means, that the edges of the spool lands are precisely made to line up with the metering ports in the valve sleeve. The reason for the accurate axial fit is to eliminate a dead zone.

Thus any movement of the spool in either direction from its centered position will cause a corresponding flow. The position of the spool in the sleeve controls both flow rate and direction of flow.

14.4.4. Application of Hydromechanical Servo Valve (Hydromechanical Servo System)

Mechanical-type servo valves are generally employed in the less complex systems. Application for hydromechanical servo valves are on : steering devices (such as power steering system of automobiles); test and training devices; copying devices (such as on machine tools); and heavy-duty mobile equipment. Now we shall discuss on the automotive power-steering application.

14.4.5. Automotive Power-Steering Application of Hydromechanical Servo System

14.4.5.1. Construction

The construction and operation of an automotive power-steering application of hydromechanical servo system (closed-loop system) is illustrated in Fig.14.3.

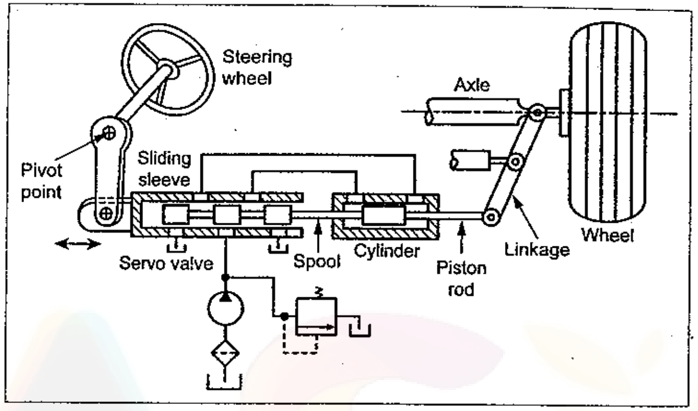


Fig. 14.3. Automotive power-steering application of mechanical-hydraulic servo system

14.4.5.2. Operation

The functioning of this hydromechanical servo system is as follows :

1. The turning of the steering wheel is the input or command signal to the servo system.
2. The steering wheel moves the valve sleeve that ports oil to the steering cylinder (actuator).
3. Now the piston rod moves the wheel through the steering linkage, as shown in Fig.14.3.
4. Since the valve spool is attached to the linkage, the valve spool moves with linkage.
5. When the valve spool has moved far enough, it cuts off oil flow to the cylinder. This stops the motion of this cylinder.
6. Thus the position of the steering wheel determines the motion of the output wheel to the desired position. To cause the further motion of the output wheel, additional motion of the steering wheel is required.

Thus a given input motion (motion of steering wheel) has produced a specific and controlled amount of output motion (motion of output wheel) and also the output motion is fedback to modify the input via the feedback line (here it is the mechanical feedback recentre called 'null'[†])

[†] Null is the relational condition between the spool and valve port where the valve supplies no control flow at zero load pressure drop. The change in null bias resulting from changes in operating conditions or environment is called ***null shift.***

14.5. ELECTROHYDRAULIC SERVO VALVE

14.5.1. What are Electrohydraulic Servo Valves ?

- ✓ The growth and popularity of electric control systems has resulted in the development of the electrohydraulic servo valve.
- ✓ The electrohydraulic servo valve operates due to an electrical signal to its torque motor which positions the spool of the DC valve. In simple terms, if the electrical signal is used as an input (or control) signal to control the hydraulic output, then it is known as electrohydraulic servo valve.
- ✓ Usually the process control standard current loop signal of 4 to 20 mA is used as an electrical control signal.
- ✓ *Applications :* Nowadays, the electrohydraulic servo controls are widely employed in industries, especially in more sophisticated control systems such as on tape-controlled machine tools, high-speed printing presses, press brakes, *etc.*

14.5.2. Advantages of Electrohydraulic Servo Systems

The electrohydraulic servo systems are used widely in fluid power industries because it offers many advantages when compared to hydromechanical servo systems. Table 14.1 lists some of the main advantages of the electrohydraulic servo systems.

Table 14.1. Advantages of electrohydraulic servo systems
(over hydromechanical servo systems)

1.	The electrohydraulic servo systems can easily achieve the precision remote control of position, force and speed of actuator.
2.	They guarantee the higher flexibility of operation.
3.	The ensure better control of fluid-compressibility, system-stiffness, and dynamic behaviour of load.
4.	They also ensure correct ratio of force and speed that leads to higher energy conversion.
5.	They have higher system performance and higher operating efficiency.
6.	They enhance easy operator control with failsafe features and higher reliability.
7.	They ensures less down time due to less mechanical failures.
8.	They achieve higher machine utilisation and less maintenance cost.

14.5.3. Types of Electrohydraulic Servo Valves

The four important types of electrohydraulic servo valves are :

1. Single-stage electrohydraulic servo valve,
2. Two-stage electrohydraulic servo valve,
3. Jet pipe electrohydraulic servo valve, and
4. Flapper jet electrohydraulic servo valve.

14.5.4. Single-Stage Electrohydraulic Servo Valve

14.5.4.1. Construction

The construction ad operation of a typical single-stage electrohydraulic servo valve is illustrated in Fig.14.4.

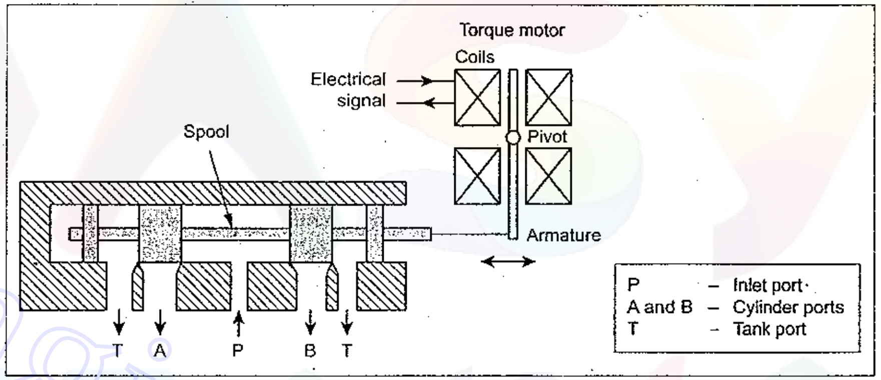


Fig. 14.4. Single-stage electrohydraulic servo valve

14.5.4.2. Operation

First the electrical signal passes through the coils of a torque motor. The torque motor produces an armature deflection proportional to its input current. Since the armature of the torque motor is connected directly to one end of the valve spool, the spool also shifts by a distance proportional to change in current.

14.5.4.3. Limitation

Single-stage servo valves are practical only for limited flows. Because the force required to move the spool at higher flow cannot be achieved.

14.5.5. Two-Stage Electrohydraulic Servo Valve

Two-stage servo valves are the most commonly used electrohydraulic servo valves in industries. Because they can handle large flow at high pressure with a high sensitivity to control changes.

14.5.5.1. Construction

The construction and operation of a typical two-stage spool-type servo valve is illustrated in Fig.14.5. The two-stage configuration uses a pilot stage and a main stage.

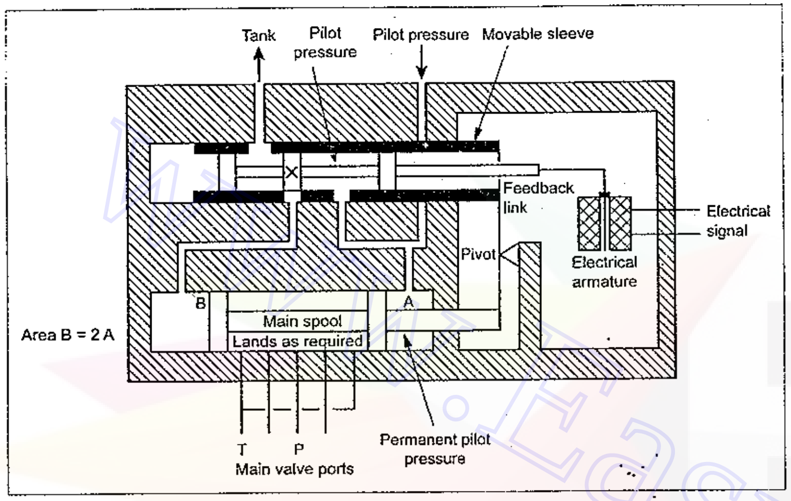


Fig. 14.5. Two-stage electrohydraulic servo valve

As shown in Fig.14.5, this arrangement consists of a small pilot spool connected directly to the small spool of the pilot valve. The pilot spool moves within a sliding sleeve, mechanically linked to the main spool. The main spool valve is designed in such a way that the effective area of the left hand end of the main spool is twice that of the right hand end.

14.5.5.2. Operation

The operation is as follows :

1. The input electrical signal produces an armature deflection by an amount proportional to the command signal.
2. The armature deflection is mechanically transmitted to the pilot spool by means of a stiff connecting wire. The direction of motion of the pilot spool depends on the input electrical signal.
3. Suppose the electrical control signal causes the pilot spool to shift towards left. Now the land X allows the oil flow to the end B of the main spool. Since area B = 2A (Fig.14.5), the main spool shifts towards the right. This in turn pushes the sleeve left. The main valve stops moving when the hole in the pilot sleeve exactly aligns with the land on the pilot spool.
4. A change in electrical signal moving the pilot spool to the right reduces pressure at the left-hand end of the main spool by bleeding fluid back to the tank. This causes the main spool to move left until pilot sleeve and pilot lands are aligned. Thus the main spool valve follows the pilot spool with equal, but opposite movements.
5. The feedback linkage mechanically connects the main spool and pilot spool sleeve. So any movement of the main spool is fed back to the pilot spool sleeve.

Thus the two-stage servo valve can provide an extremely accurate flow modulation for fast and precise control of position, velocity and acceleration of the actuator.

14.5.6. Jet Pipe Electrohydraulic Servo Valve

14.5.6.1. Construction

The construction and operation of a typical jet pipe electrohydraulic servo valve is illustrated in Fig.14.6. This design consists of a jet pipe which is linked mechanically to the main spool.

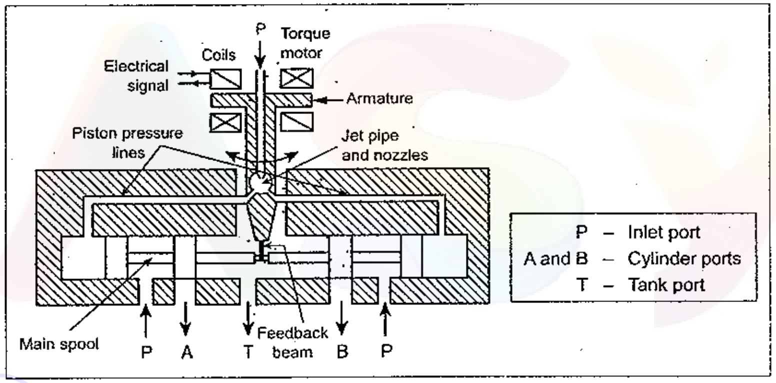


Fig. 14.6. Jet pipe servo valve

14.5.6.2. Operation

In this design, the pilot pressure is applied to a jet pipe which directs the flow into two pilot lines. The amount of flow in these two pilot lines vary depending on the input electrical control signal. Therefore the control signal diverts the jet flow into two unequal flows. These unequal flows apply unequal pressures at ends of the main spool.

Thus the main spool moves towards lesser pressure side. The spool movement stops when the jet pipe is centrally located over the two pilot pipes. This occurs when the main valve spool movement exactly balances the electrical control signal. The feedback to the flapper is provided by internal mechanical leakage or an electrical signal.

14.5.7. Flapper Jet Electrohydraulic Servo Valve

Flapper jet servo valve is actually the inverse of the jet pipe servo valve.

14.5.7.1. Construction

The construction and operation of a typical flapper jet type electrohydraulic servo valve is illustrated in Fig.14.7.

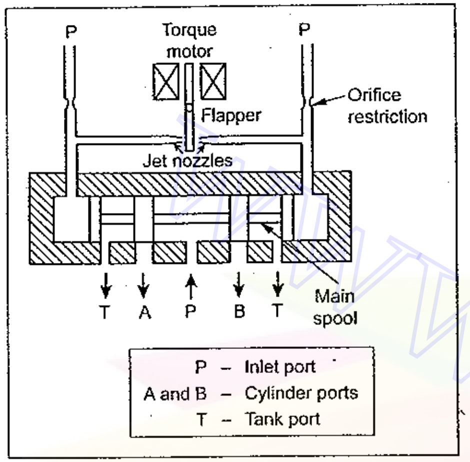


Fig. 14.7. Flapper jet servo valve

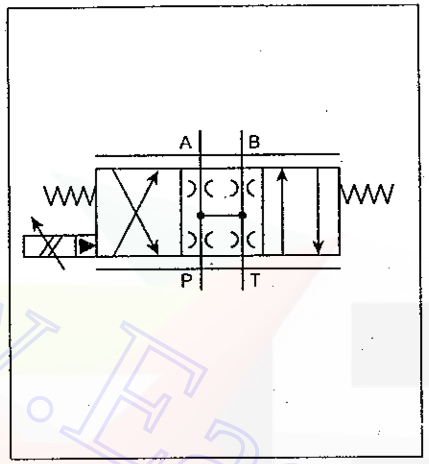


Fig. 14.8. Graphic symbol of a four-way servo valve

14.5.7.2. Operation

In this type, pilot pressure is applied to both ends of the main spool and the sliding spool is actuated by pressure differentials between each end. The pilot pressure lines are linked by two opposing jet orifices against a 'flapper' valve. This flapper valve is attached to the armature.

The input electrical signal produces an armature deflection, which in turn deflects the flapper towards one of the jet nozzles. This causes the pressure imbalance.

Now the main spool moves until the pressure is balanced on both the ends. It may be noted that the spool moves in proportion to the movement of the flapper valve, which in turn is proportional to the input current. Therefore the volume of fluid passing through the valve is proportional to the input current.

14.5.7.3. Graphic Symbol

Fig. 14.8 shows the graphic symbol of a four-way servo valve.

14.5.8. Electrohydraulic Servo System

14.5.8.1. Construction

Fig. 14.9 illustrates a circuit that uses a closed-loop electrohydraulic servo control system. This circuit is very much similar to the open loop hydraulic circuit except that a servo valve replaces the flow control and directional valves.

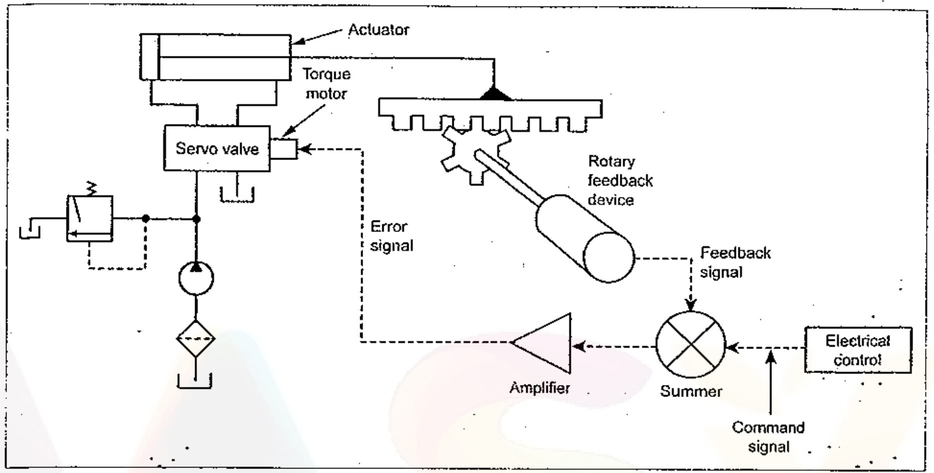


Fig. 14.9. Electrohydraulic servo system

14.5.8.2. Operation

In this servo system, a feedback device which is attached to the hydraulic actuator senses the actuator position or speed and transmits a corresponding electrical signal to the servo valve. This feedback signal is compared with electrical input signal. Suppose the actuator position or speed is not that intended, then the electronic summer will generate an error signal. This error signal is amplified and fed to the torque motor to correct the difference.

Therefore electrohydraulic servo valves can provide very accurate control relative to position, speed, pressure and load by incorporating the appropriate feedback devices.

PROPORTIONAL CONTROLS

14.6. PROPORTIONAL VALVES

14.6.1. What are Proportional Control Valves

- ✓ In modern electro-hydraulic systems, proportional control valves are used as an alternative to servo valves.
- ✓ Proportional control valves offer a high degree of flexibility in automatic programmed circuits.
- ✓ Proportional valves are available to regulate and control movement and pressure by varying an electrical input signal. These input signals may be provided by a simple potentiometer or by complex electronic hardware.

- ✓ Similar to servo valves, proportional valves also use a variable force direct current solenoid to control the output from the main spool. Therefore the output is directly proportional to the input signal.
- ✓ The main advantage of proportional valves is their ability to control the pressure and flow rate proportionately and provide remote function.

14.6.2. Types of Proportional Control Valves

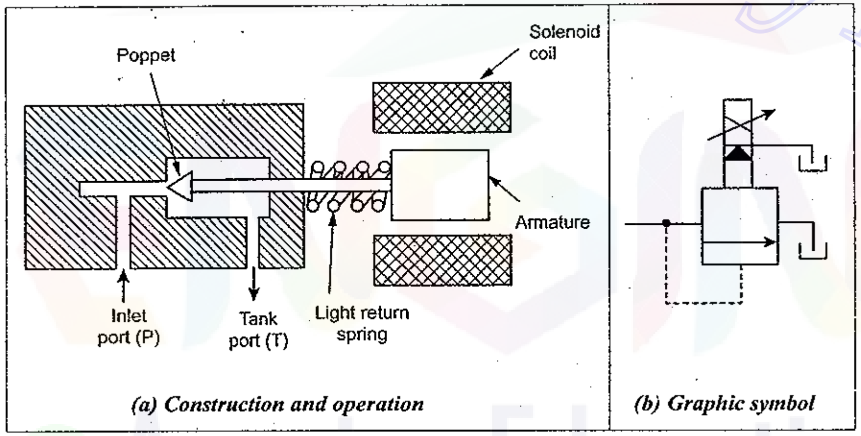
Three important types of proportional control valves are :

1. Proportional pressure relief valve,
2. Proportional pressure reducing valve, and
3. Proportional direction control valve.

14.6.3. Proportional Pressure Relief Valve

14.6.3.1. Construction

The construction and operation of a typical proportional pressure relief valve is illustrated in Fig.14.10(*a*).



(a) Construction and operation *(b) Graphic symbol*

Fig. 14.10. Proportional pressure relief valve

14.6.3.2. Operation

The proportional pressure relief valve works on exactly the same principle as the conventional pressure relief valve (described in Section 7.13), except that the compression (adjustable) springs are replaced by a proportional solenoid. In this valve, the operating pressure of the valve depends on the current in the solenoid.

The input current to the solenoid energies it coil and hence produces an armature deflection by an amount proportional to the input current. This armature deflection exerts a force on the poppet. The poppet keeps the valve closed until the inlet pressure at port P overcomes the force exerted by armature deflection. When the inlet pressure overcomes this force, then the poppet valve opens. Thus the opening and closing of the valve, and hence the operating pressure of the valve can be varied by proportionately varying the input current to the solenoid.

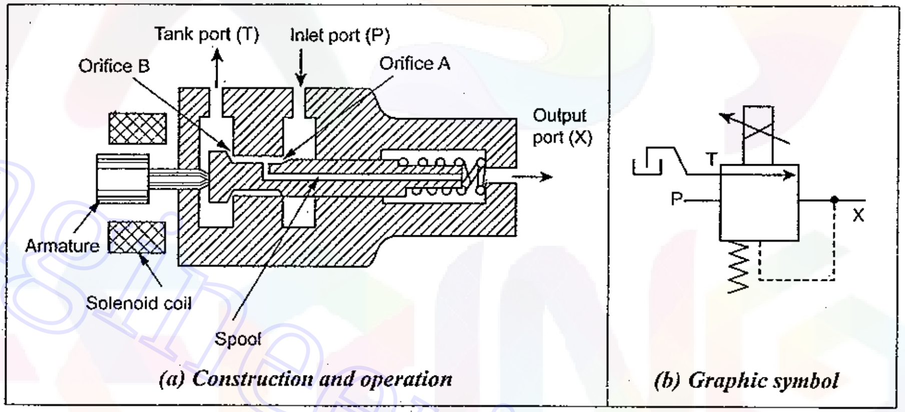
14.6.3.3. Graphic Symbol

Fig.14.10(*b*) shows the graphic symbol of the proportional pressure relief valve.

14.6.4. Proportional Pressure Reducing Valve

14.6.4.1. Construction

The construction and operation of a typical proportional pressure reducing valve is illustrated in Fig.14.11(*a*).



(a) Construction and operation *(b) Graphic symbol*

Fig. 14.11. Proportional pressure reducing valve

14.6.4.2. Operation

The proportional pressure reducing valve works on exactly the same principle as the conventional pressure reducing valve (described in Section 7.17), except that the control spring is replaced by a proportional solenoid. Also unlike the conventional pressure reducing valve, this valve is normally closed when the solenoid is not energized.

When the solenoid is energized, its corresponding armature deflection will move the spool to the right. This opens the control orifice A and allows the fluid to flow to the output port X. The outlet pressure of this valve is dependent upon the openings of control orifices A and B, which in turn depends on the input current supplied to solenoid. Thus by proportionately varying the input current to the solenoid, the operating pressures of the valves can be varied.

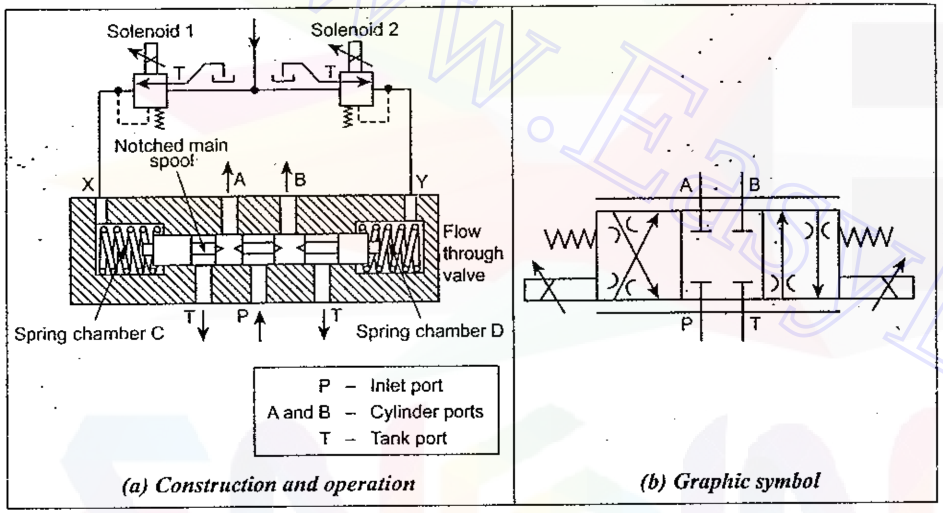
14.6.4.3. Graphic Symbol

Fig.14.11(*b*) shows a graphic symbol of proportional pressure reducing valve.

14.7. PROPORTIONAL DIRECTION CONTROL VALVE

14.7.1. Construction

The construction and operation of a typical proportional direction control valve is illustrated in Fig.14.12(*a*).



(a) Construction and operation

(b) Graphic symbol

Fig. 14.12. Proportional direction control valve

14.7.2. Operation

When solenoid 1 is energized, the pressure is applied to pilot port X. This causes the spool to move towards right against the control spring. As the main spool lands are notched, the spool movement to the right will allow the fluid flow from port P to B and from port A to T. When the solenoid is de-energized, the spring chamber C depressurises and the control spring centralises the spool to its normal position.

Similarly when solenoid 2 is energized, the pressure is applied to pilot port Y. This causes the spool to move towards left against the control spring. Now the fluid flows from port P to A and from port B to T. When the solenoid 2 is de-energized, the spool returns to its normal position.

Thus the movement of the spool is proportional to the pressures applied to the pilot ports X and Y, which in turn proportional to the current in solenoids 1 and 2.

14.7.3. Graphic Symbol

Fig.14.12(*b*) shows the graphic symbol of the proportional direction control valve.

REVIEW AND SUMMARY

✓ *In this chapter, the purpose, construction and operation of various servo and proportional control valves have been presented.*

✓ *A **servo control system** is one in which a comparatively large amount of power is controlled by small impulses or command signals and any errors are corrected by feedback signals.*

✓ *A system having a servo valve, servo amplifier and actuator connected together providing a closed loop feedback is known as a **servomechanism.***

✓ ***Servo valves** are DC valves having infinitely variable positioning capability. The servo valves are used to control not only the direction of fluid flow but also the amount of flow.*

✓ *When servo values are coupled with feedback devices, they can be used to control the position, velocity, and acceleration of the actuator accurately.*

✓ ***Types of servo valves :** The important types of servo valves are :*

1. *Mechanical-type servo valve, and*
2. *Electrohydraulic servo valve.*
    - *(i) Single-stage servo valve,*
    - *(ii) Two-stage servo valve,*
    - *(iii) Jet pipe servo valve, and*
    - *(iv) Flapper jet servo valve.*

✓ *If the electrical signal is used as an input (or control) signal to control the hydraulic output, then it is known as **electrohydraulic servo valve.***

✓ ***Proportional valves,** similar to servo valves, use a variable force direct current solenoid to control the output from the main spool. Therefore the output is directly proportional to the input signal.*

✓ ***Types of proportional control valves :** Three important types of proportional control valves are :*

- *(i) Proportional pressure relief valve,*
- *(ii) Proportional pressure reducing valve, and*
- *(iii) Proportional direction control valve.*

✓ *Both proportional type pressure relief and pressure reducing valves work on the same principle as similar conventional pressure relief and pressure reducing valves, except that the adjustable springs are replaced by proportional solenoids.*

KEY TERMS ONE SHOULD REMEMBER

- Servo control systems
- Servo systems
- Closed-loop
- Command signal
- Servo amplifier
- Feedback transducer
- Servomechanism
- Servo valves
  - Hydro mechanical servo valves
  - Electrohydraulic servo valves
    - Single stage servo valves
    - Two stage servo valves
  - Jet pipe servo valves
  - Flapper jet servo valves
- Proportional valves
  - Proportional pressure relief valves
  - Proportional pressure reducing valves
  - Proportional direction control valves

REVIEW QUESTIONS

Short Answer Type Questions

1. What is a servo system ?
2. List six elements of a basic closed-loop servo system.
3. Write the functions of the following : (*a*) Servo amplifier, and (*b*) Feedback transducer.
4. What are servo valves ? Write their purpose in fluid power systems.
5. How can you classify servo valves ?
6. Define the terms 'lap' and 'null' with respect to servo valves.
7. What do you mean by zero lap servo valve ?
8. Mention any four applications of hydromechanical servo valves.
9. What are electrohydraulic servo valves ? How do they differ from hydromechanical servo valves ?
10. Write few applications of electrohydraulic servo valves.
11. What are the advantages of electrohydraulic servo systems over hydromechanical servo systems ?
12. Differentiate between single-stage and two-stage servo valves.
13. What are proportional control valves ?
14. Draw the graphic symbols for the following valves :

(*i*) Four-way servo valve, (*ii*) Proportional pressure relief valve,
(*iii*) Proportional pressure reducing valve, and (*iv*) Proportional direction control valve.

Essay Answer Type Questions

1. (*a*) With a neat sketch, explain the operation of a hydromechanical servo valve.
   (*b*) Illustrate an automotive power-steering application of hydromechanical servo system, with the help of a neat sketch.
2. Explain the construction and operation of a two-stage electrohydraulic servo valve.
3. Compare and contrast the operation of a jet pipe and a flapper jet electrohydraulic servo valves with suitable sketches.
4. With a circuit diagram, explain the operation of any one application of a closed-loop electrohydraulic servo system.
5. Discuss the construction and operation of a proportional direction control valve with the help of a sketch.
6. Explain the operation of a proportional (*i*) pressure reducing valve, and (*ii*) pressure relief valve.

□□

Chapter 15

Logic Controls in Fluid Power Systems

"In contrast with the scientist, whose main interest is in discovering new knowledge, the engineer's greatest enjoyment derives from creatively solving practical problems."

—Ibid

"The turning point in the process of growing up is when you discover the core of strength within you that survives all hurt."

—A.P.J. Abdul Kalam

"One who fears failure limits his activities. Failure is the only opportunity to more intelligently begin again."

—Henry Ford

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Understand the technology of fluidics and how fluidics is used to control fluid power systems.

☑ Discuss the construction, operation and purpose of the various fluidic devices.

☑ Explain the construction, operation and features of the various types of fluid sensors.

☑ Apply and design fluidic logic circuits for various fluid power systems.

☑ Understand the distinct features of moving-part logic (MPL) devices.

☑ Appreciate the role of PLCs in fluid power control systems.

☑ Apply ladder logic diagrams and Boolean algebra to programmable logic control of fluid power systems.

CHAPTER 15 LOGIC CONTROLS IN FLUID POWER SYSTEMS

15.1. INTRODUCTION

Whenever some industrial processes or a machine is to be automatically controlled, then a suitable control system is to be employed. The various control methods employed are mechanical control systems, electro-mechanical control systems, electro-hydraulic control systems, electro-pneumatic control systems, hydropneumatic or pneumohydraulic control systems, and electronic control systems.

Nowadays, fluid power industries demand higher machine reliability and the elimination of down time due to component part failure wherever possible. Also, industries demand multifunctional equipment that offers flexibility in control circuits and provision for rapid change-over due to constantly changing manufacturing methods. The conventional types control systems mentioned above prove to be totally inadequate to meet these requirements of industries.

The technology of fluidics (*i.e.*, fluid-logic control system) promises to fulfill most of these requirements. Fluidics is the technology that utilises fluid flow phenomena in components and circuits to perform a wide variety of control functions. These fluid-logic control system is becoming increasingly more popular because it offers some outstanding advantages (such as exceptional thermal and physical stability and ruggedness, insensitiveness to radiation, very minimal vibration and shock, *etc.*) over the conventional alternate control system methods.

In this chapter, we shall understand the technology of fluidics and how fluidics is used to control fluid power systems. At the end of the chapter, the brief note on moving-part logic (MPL) control systems and programmable logic controllers (PLCs) will also be presented.

FLUIDICS

15.2. FLUIDICS

15.2.1. What is Fluidics ?

✓ *Fluidics is the technology that utilizes fluid flow phenomena in components and circuits to perform a wide variety of control functions.* These control functions include sensing, logic, memory, timing, and interfacing to other control media.

- ✓ The term 'fluidics' is derived from two words 'fluid' and 'logic'. It is used specifically to describe the technology of the control of fluid force components by means of devices utilizing fluid interaction phenomena to produce useful output signals.
- ✓ The fluidic devices control fluid power force components and fluid power master control components by the same media with which the force components are operated—either gases or liquids.
- ✓ In other words, fluidic devices perform their control function by a stream of gas or liquid directing itself through precision channels. The flow of media (stream of as or liquid) in this control method is quite similar to the apparent flow of electricity through wires and contact points.

15.2.2. Advantages of Fluidic Control Systems

The basic characteristics of using fluids to control themselves offer various advantages over the conventional alternate control methods. Some of the important advantages of fluidic control systems are given below :

1. Fluidic devices offer exceptional thermal and physical stability and ruggedness, when compared to electronic control systems. (Through the electronic logic control systems are widely used, they are affected by temperature, shock, vibration, and radiation.)
2. Fluidic devices are completely insensitive to radiation, even of extremely high levels.
3. Fluidic devices are not affected by severe vibration and shock.
4. Unlike hydraulic and pneumatic control components, fluidic devices are not susceptible to wear and tear. In other words, since fluidic components do not have any moving parts, they virtually do not wear out.
5. Simpler construction and easier maintenance.
6. Highly reliable functionality.
7. Relatively low cost.
8. Interfacing capability can be easily accomplished with fluidics. Fluidic components can be interfaced to control pneumatic, electrical, or other systems.
9. Since air is normally used as the working fluid within these devices, there are no problems of electrical noise, vibration, fatigue and contact contamination.
10. Since there is no arcing or sparking of switching elements, circuits employing fluidic devices can be operated quite safely in highly explosive or other dangerous environments.

15.2.3. Drawbacks of Fluidic Control Systems

The two noteworthy drawbacks of fluidic control systems are :

1. Reaction time of fluidic control system is somewhat lower than that of electronic systems. However, fluidic devices do respond in milliseconds or speeds that are quiet adequate for most requirements.

2. Fluidic components normally operate at low power and pressure levels (below 1 bar). However these low-pressure signals can reliably control hydraulic systems operating with upto 700 bar or to provide the muscle to do useful work at rates upto several hundred horse power.

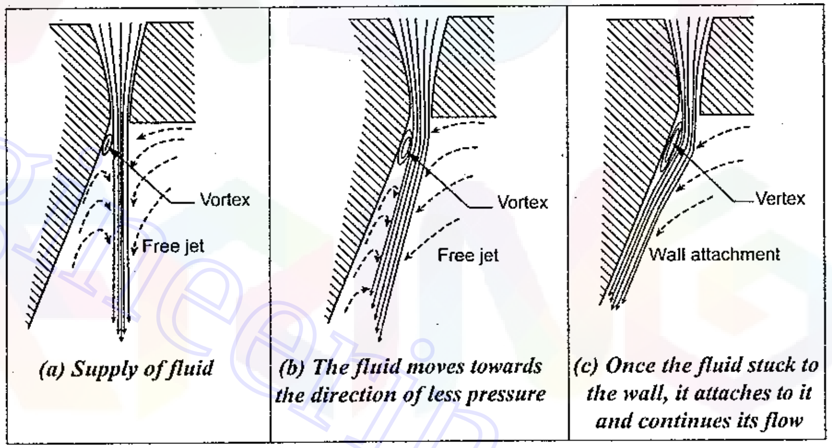
15.3. PRINCIPLE OF FLUIDIC LOGIC CONTROL ('Coanda Effect' or 'Wall-Attachment' Effect)

15.3.1. What is a 'Coanda Effect' ?

- ✓ The 'Coanda[†] effect', also known as ***'Wall-Attachment effect'***, is the basis for functioning of many fluidic components and the fluidic technology itself.
- ✓ ***'Coanda effect' defined :*** *"When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."*

15.3.2. Illustration of Coanda Phenomenon

Figs.15.1(*a*), (*b*) and (*c*) illustrate the wall-attachment phenomenon.



(a) Supply of fluid

(b) The fluid moves towards the direction of less pressure

(c) Once the fluid stuck to the wall, it attaches to it and continues its flow

Fig. 15.1. Illustration of the wall-attachment phenomenon

As shown in Fig.15.1(*a*), a free fluid jet (*i.e.*, a stream of air/liquid) passing through an orifice will continue in a given direction, pulling in with it any available fluid that surrounds the jet as it leaves the orifice.

When there is greater availability of this entraining air from one side than from the other (Fig.15.1(*b*)), then a small vertex area (having a low pressure) is created near the nozzle exit. This low pressure area tends to attract the free jet, distorting it and pulling it toward the angled wall.

[†] It is named after a Rumanian engineer Henn Marie Coanda who has developed it in 1932.

Once this free jet is pulled tangent to the exit wall, the continued existence of this vortex tends to hold the jet attached to that wall, as shown in Fig.15.1(c). That's why this phenomenon is termed as the 'wall-attachment' phenomenon.

15.3.3. Visual Demonstration of Coanda Effect

Fig.15.2 illustrates a simple self-explanatory, visual demonstration of Coanda effect. When a finger is held near the stream of water flowing at from the water-tap, then one can see that the water attaches itself to the figure as shown. This is clearly due to the Coanda effect.

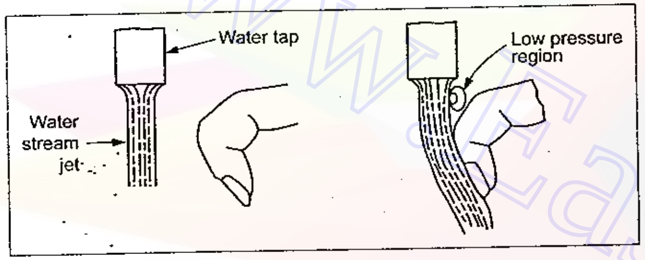


Fig. 15.2. Visual demonstration of the Coanda effect

15.4. BASIC FLUIDIC DEVICES

Some important basic fluidic devices are :

1. Basic bistable flip-flop,
2. Flip-flop with start-up preference,
3. SRT flip-flop,
4. OR/NOR gate,
5. AND/NAND gate, and
6. Exclusive OR gate.

Now we shall discuss the operation of the above fluidic devices in the following sections.

15.4.1. Basic Bistable Flip-Flop

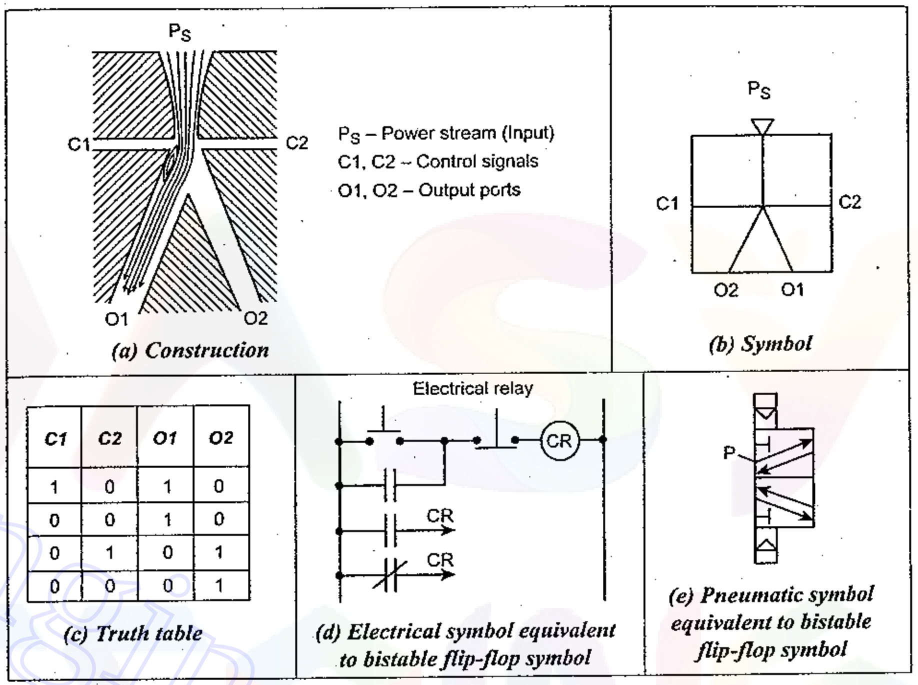
A basic bistable flip-flop provides controlled assurance as to which of the two output ports will deliver the power stream.

15.4.1.1. Construction

A basic bistable flip-flop is illustrated in Fig.15.3(a). Figs.15.3(b) and (c) show the symbol and truth table of the basic bistable flip-flop respectively. Figs.15.3(d) and (e) show the equivalent electrical and pneumatic symbols for the bistable flip-flop function respectively.

15.4.1.2. Operation

In this device, the air flow will be from input power stream (P_s) to either the O1 output port or the O2 output port, depending on the existence of a signal from either C1 channel or C2 channel. This device operates on the principle of the low pressure vortex being created on one side or the other of the element, creating the wall-attachment effect toward either the O1 or O2 output ports.


Ps
C1
C2
O1
O2
Ps – Power stream (Input)
C1, C2 – Control signals
O1, O2 – Output ports
(a) Construction
Ps
C1
C2
O2
O1
(b) Symbol
Electrical relay
CR
CR
CR
(d) Electrical symbol equivalent to bistable flip-flop symbol
P
(e) Pneumatic symbol equivalent to bistable flip-flop symbol

C1	C2	O1	O2
1	0	1	0
0	0	1	0
0	1	0	1
0	0	0	1

(c) Truth table

Fig. 15.3. Basic bistable flip-flop

The bistable flip-flop derives its name from the fact that it has two stable conditions, O1 and O2, and it can be made to switch or flip from one to the other.

15.4.1.3. Use

The bistable flip-flop device is normally used as a memory device. This can be understood from the symbol and truth table of the bistable flip-flop, as shown in Figs.15.3(b) and (c).

15.4.1.4. Truth Table

A truth table helps to describe the functioning of that particular device. In truth table, the number O refers OFF and the number 1 refers ON for all devices. From the truth table of bistable flip-flop (Fig.15.3(c)), one can interpret the following points :

- ✓ ***For the first row :*** "When control signal C1 is ON and control signal C2 is OFF, then the output is at O1 (and there is no output at O2).
- ✓ ***For the second row :*** If both control signals C1 and C2 are turned OFF, then the output is at O1.

- ✓ ***For the third row :*** When C1 is turned OFF and C2 is ON, then the output is at O2.
- ✓ ***For the fourth row :*** Now, removing the signal C2 leaves the device at the second stable state with the output of O2.

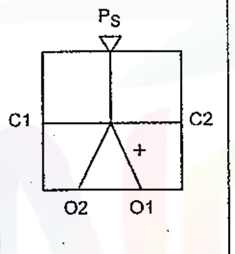
Thus the flip-flop has two stable states when all control signals are OFF. Also when both control signals C1 and C2 are turned ON simultaneously, the supply pressure splits and there is no useful output to such condition. Thus when both C1 and C2 are ON, the flip-flop does not produce useful digital ON/OFF output signals.

15.4.2. Flip-Flop with Start-up Preference

A flip-flop with start-up preference is used in applications where a specific output is required when the power supply is first turned ON and all controls are OFF.

15.4.2.1. Construction

The construction and operation of the flip-flop with start-up preference is very much similar to that the basic flip-flop. The symbol and truth table of the flip-flop with start-up preference are shown in Figs.15.4(*a*) and (*b*) respectively.



(a) Symbol

C1	C2	O1	O2
0	0	1	0
0	1	0	1
0	0	0	1
1	0	1	0
0	0	1	0

(b) Truth table

Fig. 15.4. Symbol and truth table for preferenced flip-flop

15.4.2.2. Operation

In Fig.15.4(*a*), the plus (+) sign indicates that the output O1 is preferred over O2. This can be accomplished by building the splitter slightly off center. That's why when the flip-flop first receives its power supply (and control signals are OFF), the wall attachment is preferenced to the O1 output.

15.4.2.3. Truth Table

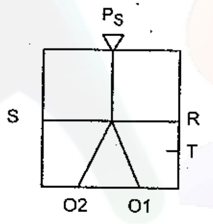
The only difference of the truth table (Fig.15.4(*b*)) of preferenced flip-flop over the truth table (Fig.15.3(*c*)) of basic flip-flop is that when all control signals are OFF, the output is ON at O1 and OFF at O2 (as shown in the first row of the Fig.15.4(*b*)). All the remaining functions are exactly the same as that of basic flip-flop (which can be seen from the last four rows of both Figs.15.4(*b*) and 15.3(*c*)).

15.4.3. SRT Flip-Flop

In addition to all the capabilities of a basic flip-flop, a SRT flip-flop can also switch by applying a signal to the trigger port. *The name SRT flip-flop is an acronym for SET-RESET-TRIGGER flip-flop.*

15.4.3.1. Construction

The symbol and truth table for a SRT flip-flop are shown in Figs.15.5(*a*) and (*b*) respectively. In Fig.15.5(*a*), the letters 'S' and 'R' stand for SET and RESET respectively. They perform as regular control signals similar to C1 and C2 in basic flip-flops. The letter 'T' stands for TRIGGER, whenever trigger signal is applied, it switches the output.



(a) Symbol

T	S	R	O1	O2
0	1	0	1	0
0	0	0	1	0
0	0	1	0	1
0	0	0	0	1
1	0	0	1	0
0	0	0	1	0
1	0	0	0	1
0	0	0	0	1

(b) Truth table

Fig. 15.5. Symbol and truth table for SRT flip-flop

15.4.3.2. Operation

The readers can read and understand the symbol and truth table of the SRT flip-flop in the same manner as discussed earlier. In Fig.15.5(*b*), the first column shows the status of the trigger control signal. Whenever this trigger (T) signal is turned ON, it switches (compliments) the output.

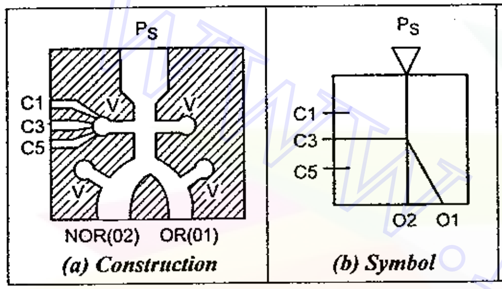
15.4.4. OR/NOR Gate

15.4.4.1. What do you mean by a Monostable Device ?

- ✓ Further developments of the basic flip-flops led to the monostable device with more than one control input.
- ✓ A monostable device is required to perform monostable function which is analogous to spring return function. In this device, when the control signal is removed, the device will switch back to the favoured output.
- ✓ The basic flip-flop, preferenced flip-flop and SRT flip-flop—discussed so far—are all bistable devices. They perform basically memory functions.
- ✓ The two important monostable fluidic devices are :
  1. OR/NOR gate, and
  2. AND/NAND gate.

15.4.4.2. Construction of OR/NOR Gate

The construction and operation of an OR/NOR gate is illustrated in Fig.15.6(*a*). Figs.15.6(*b*) and (*c*) show its symbol and truth table respectively. In this, the O1 port represents the OR output and the O2 port represents the NOR output.



(a) Construction *(b) Symbol*

		OR	NOR
C1	C3	O1	O2
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

(c) Truth table

Fig. 15.6. OR/NOR gate

15.4.4.3. Operation

The OR/NOR gate has two outputs corresponding with two conditions :

(*i*) OR(01)—pressure at one or any combination of the control ports; and

(*ii*) NOR(02)—pressure at none of the control ports.

A control signal at any one or any combination of these ports will switch the device to the O1 output. With all control signals OFF, the device will be automatically switched to O2 output. Normally the OR/NOR gate is designed in such a manner that flow will always be in the NOR leg when no control signal is present. Also OR/NOR gate is available with multiple input signals, as shown in Fig.15.6(*b*).

15.4.4.4. Notations Representing Operations

The desired practice, while describing fluidic components or designing circuits, is to use standard logic notation. Some of the standard logic notations are given below :

(*i*) A • (dot means AND).

(*ii*) +(plus sign) means OR.

(*iii*) Bar over a letter ($\overline{A}$) means that the condition represented by the "A" is absent. This notation is read as 'NOT A'.

Using the above notations, the operation of the OR/NOR gate can be written as follows :

$$\boxed{\begin{aligned} O1 &= C1 + C3 = OR \\ O2 &= \overline{C1}\cdot\overline{C3} = NOR \end{aligned}}$$

It should be noted that NOR means NOT OR. ∴ NOR = NOT OR = $\overline{OR}$.

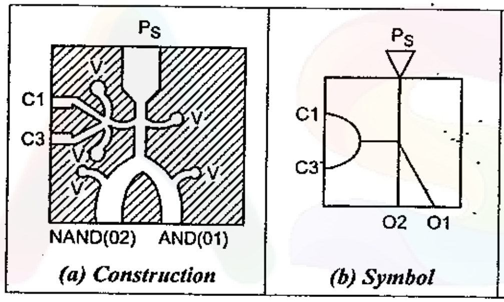
15.4.4.5. Uses

The OR/NOR gate is the basic logic building block. The OR/NOR block can be used in various ways to achieve all of the other logic functions.

15.4.5. AND/NAND Gate

15.4.5.1. Construction

The construction and operation of an AND/NAND gate is illustrated in Fig.15.7(*a*). Figs.15.7(*b*) and (*c*) show its symbol and truth table respectively. Fig.15.8 gives the equivalent electrical and pneumatic symbols for the AND/NAND gate functions.



(a) Construction *(b) Symbol*

		AND	NAND
C1	C3	O1	O2
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

(c) Truth table

Fig. 15.7. AND/NAND gate

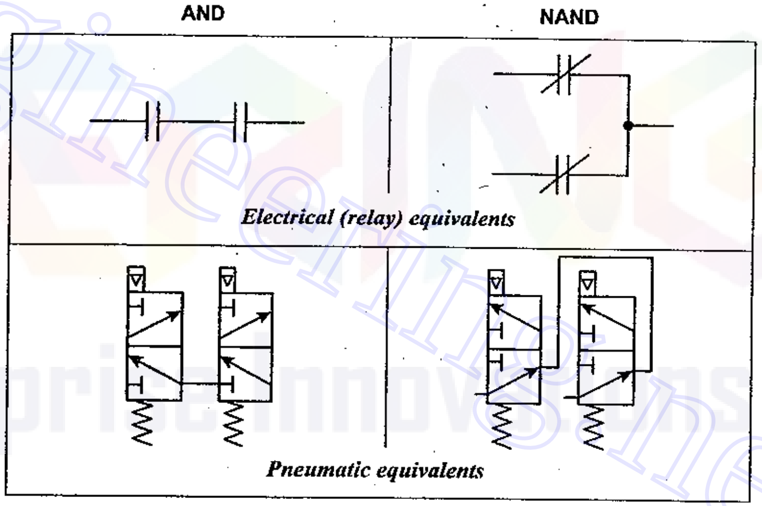


Fig. 15.8. Equivalent electrical and pneumatic symbols for AND and NAND gate functions

15.4.5.2. Operation

The operation of AND gate is similar to the NOR gate, except that the NOR gate is used to determine when none of the controls is present [see first row in Fig.15.6(*c*)], whereas the

AND gate is used to determine when all the control signals are present [see the last row in Fig.15.7(*c*)].

In Fig.15.7(*b*), both the C1 and C3 control signals must be present to get an output at the O1 port (AND function). The absence of either or both will result in the stable output at the O2 port (NAND function).

Using the logic notations, the operations of the AND/NAND gate can be written as follows :

$$\boxed{\begin{aligned} O1 &= C1 \cdot C3 = \text{AND} \\ O2 &= \overline{C1} \cdot \overline{C3} = \text{NAND} \end{aligned}}$$

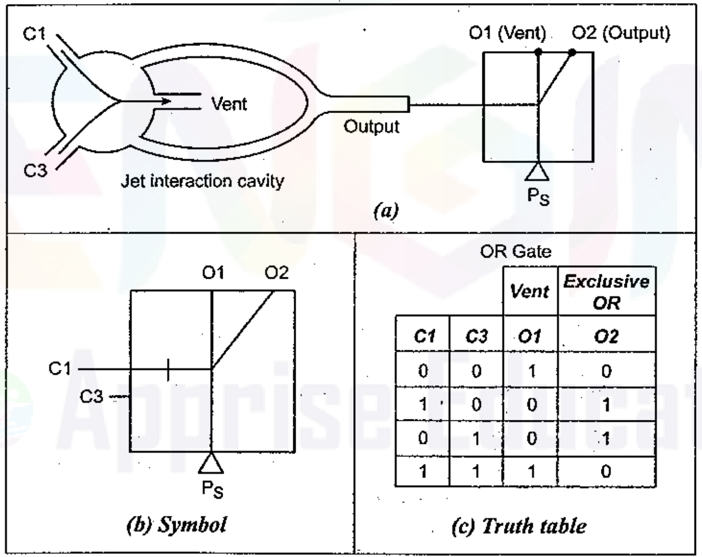
It should be noted that NAND means NOT AND. ∴ NAND = NOT AND = $\overline{\text{AND}}$

15.4.6. Exclusive OR Gate

An exclusive OR gate is a device that provides an output only when C1 or C3 or C5 or C7 (but not any combination of control signals) is ON.

15.4.6.1. Construction

The construction and operation of an exclusive OR gate is illustrated in Fig.15.9(*a*). Figs.15.9(*b*) and (*c*) show its symbol and truth table.



(*b*) Symbol

		Vent	Exclusive OR
C1	**C3**	**O1**	**O2**
0	0	1	0
1	0	0	1
0	1	0	1
1	1	1	0

(*c*) Truth table

Fig. 15.9. An exclusive OR gate

15.4.6.2. Operation

The exclusive OR gate is obtained by feeding the output of a jet interaction cavity into the control port of an OR gate, as shown in Fig.15.9(*a*).

When control signal C1 or C3 is ON, the jet interaction cavity produces an output at O2 port. This can be seen in the 2nd and 3rd rows of the truth table (Fig.15.9(*c*)).

When both C1 and C3 control signals are ON, then their interaction causes them to vent to the atmosphere and hence there is no output at port O2. This can be seen in the 4th row of the truth table [Fig.15.9(*c*)].

Note ✓ The truth tables are formed based on the concept known as 'Boolean Algebra'.

✓ ***Boolean algebra*** is an 'algebra of logic[†]'. This system formulated logical statements symbolically so that they could be written and proven in a similar manner as used in ordinary algebra. This is the algebra of proportions where only two possibilities—true or false—are allowed. In Boolean algebra, only two numbers—0 and 1—are used.

✓ ***Functions :*** Boolean algebra provides the following two functions relative to fluid power systems :

1. It provides a means by which a logic circuit can be reduced to its simplest form.
2. It allows for the quick synthesis of a circuit that is to perform desired logic operations.

✓ For more details on various laws of Boolean algebra, refer Appendix I, Article 7.

15.5. FLUID SENSORS

15.5.1. What are Fluid Sensors ?

✓ *Fluid sensor is a device that senses a change in some parameter and as a result causes a related change in another parameter that can be recognized and interpreted.*

✓ Various types of fluid sensors are used in machine tools and other systems to transmit and receive signals so as to control the actuator speed, position, and pressure.

15.5.2. Types of Fluid Sensors

The four important types of fluid sensors relative to fluid power systems are :

1. Back-pressure sensor,
2. Cone-jet proximity sensor,
3. Interruptible-jet sensor, and
4. Contact sensing.

Now we shall discuss the construction and operation of the above said fluid sensors in the following sections.

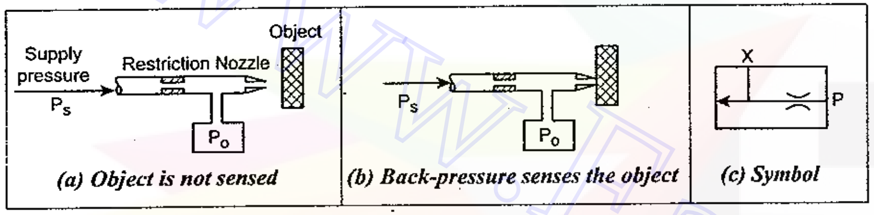
[†] The term 'logic' may be defined as the science that deals with the canons and criteria of validity in thought and demonstration. It is the science of the formal principles of reasoning.

15.5.3. Back-Pressure Sensor

The back-pressure sensor works on the principle that the fluid when passed through a nozzle or a restricted passage always has a pressure difference.

15.5.3.1. Construction

The construction and operation of a typical back-pressure sensor is illustrated in Fig.15.10.



(a) Object is not sensed *(b) Back-pressure senses the object* *(c) Symbol*

Fig. 15.10. Back-pressure sensor

15.5.3.2. Operation

In this sensor, continuity of fluid flow through the nozzle is disrupted by advancing mechanical objects, which creates a back pressure. This back pressure signals (*i.e.*, senses) the presence of the object.

As shown in Fig.15.10(*a*), when the nozzle is not blocked, then the difference between inlet pressure (P_s) and outlet pressure (P_o) does not change. But when the object is brought near the outlet of the nozzle [Fig.15.10(*b*)], this induces the back pressure.

Now there will be a pressure difference between P_s and P_o. This helps in the identification of the object in the path.

15.5.3.3. Symbol

Fig.15.10(*c*) shows the graphic symbol for the back-pressure sensor.

15.5.4. Cone-Jet Proximity Sensor

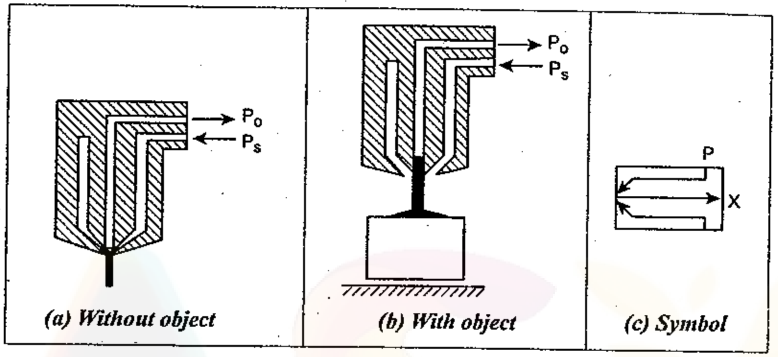
A proximity sensor can detect the objects at comparatively greater distance than is possible with a back-pressure sensor. In fact, it can sense gaps 10 times larger than the back-pressure sensor for an equivalent amount of flow consumption.

15.5.4.1. Construction

The construction and operation of a typical cone-jet proximity sensor is illustrated in Fig.15.11. This sensor uses an annular nozzle that surrounds a sensing hole.

15.5.4.2. Operation

When the sensor supply pressure (P_s) is supplied, a conical jet forms at the tip of the nozzle. This conical jet encloses a low-pressure bubble within the flow cone, as shown in Fig.15.11(*a*). Now the pressure at the sensing opening (P_o) into the base of the cone is normally slightly below the atmospheric pressure.



(a) Without object *(b) With object* *(c) Symbol*

Fig. 15.11. Cone-jet proximity sensor

When an object is brought near the flow cone as shown in Fig.15.11(*b*), a portion of supply jet is reflected from the object into the low pressure bubble region. This increases the output pressure (P_o). This increased output pressure permits the switching of the control element.

15.5.4.3. Symbol

Fig.15.11(*c*) shows a graphic symbol of a proximity sensor.

15.5.4.4. Limitations

The proximity type sensors have the following drawbacks :

1. Relatively more air consumption.
2. Relatively high cost when compared to back-pressure sensors.
3. Output pressure obtained is very low, therefore the signal amplification is required.

15.5.5. Interruptible Jet Sensor (or Gap Sensor)

15.5.5.1. Construction

The construction and operation of a typical interruptible jet sensor is illustrated in Fig.15.12. It uses a nozzle to transmit air stream across a gap to a receiver.

15.5.5.2. Operation

When the flow is unobstructed, the air is allowed to flow from P_S to P_o uninterrupted. But if a mechanical object blocks the gap, then the air jet is blocked after leaving the nozzle tip and the signal at the receiver end disappears. Thus the downstream valve which receives the signal from the outlet end may reverse.

15.5.5.3. Symbol

Fig.15.12(*b*) shows a graphic symbol for the interruptible jet sensor.

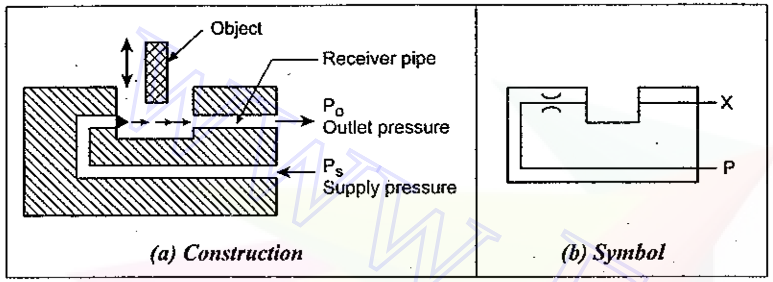


Fig. 15.12. Interruptible jet sensor

15.5.5.4. Advantages

The two advantages of using interruptible jet sensors are :

1. Simple in construction and operation.
2. Relatively inexpensive.

15.5.5.5. Limitations

The two main drawbacks of interruptible jet sensors are :

1. Only relatively thin objects can be sensed.
2. Like proximity sensors, amplification of signal is required. Because the output pressure obtainable is very low.

15.5.6. Contact Sensing (or Limit Switch)

Contact sensing is nothing but the sensing of objects by physical contact. It can be achieved by using a device called a limit valve or limit switch.

15.5.6.1. Construction

The arrangement and operation of a typical contact sensing with limit switch is illustrated in Figs.15.13(*a*) and (*b*).

15.5.6.2. Operation

The operation of this limit switch is very much similar to that of a fluidic OR/NOR gate (discussed in Section 15.4.4), except a mechanical input signal is used rather than a fluid one.

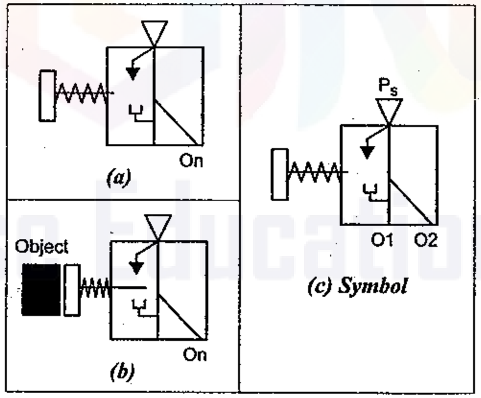


Fig. 15.13. Contact sensing with limit switch

When there is no contacting object [Fig.15.13(*a*)], the output is switched to the normally ON output. When an object contacts the actuator [Fig.15.13(*b*)], the output switches to the normally OFF output.

15.5.6.3. Symbol

Fig.15.13(*c*) shows a graphic symbol for the limit switch sensor.

15.6. FLUIDIC CONTROL OF FLUID POWER SYSTEMS

Because of the many advantages of the fluidic control systems (discussed in Section 15.2.2), they are widely used in many fluid power applications. Now we shall discuss three basic circuits where fluidics is used to control the fluid power systems.

It may be noted that fluidic circuits operate at low pressures (normally less than 1 bar) to provide the necessary logic functions to pilot-operate pneumatic valves for the control of fluid power. It should be noted that the fluidic air and air lines are kept separate from the main air supply (having high pressures from 7 bar to 10 bar) utilized by pneumatic systems.

15.6.1. Control of Air Cylinder Using Preferenced Flip-Flop

15.6.1.1. Circuit

Fig.15.14 illustrates a fluidic logic circuit that can provide the push-button start and air limit switch reversal of an air cylinder. This circuit uses two pilot-actuated 3/2 control valves (V1 and V2), a preference flip-flop, a normally closed (NC) limit switch (V3), a shuttle valve (V4), and an air cylinder.

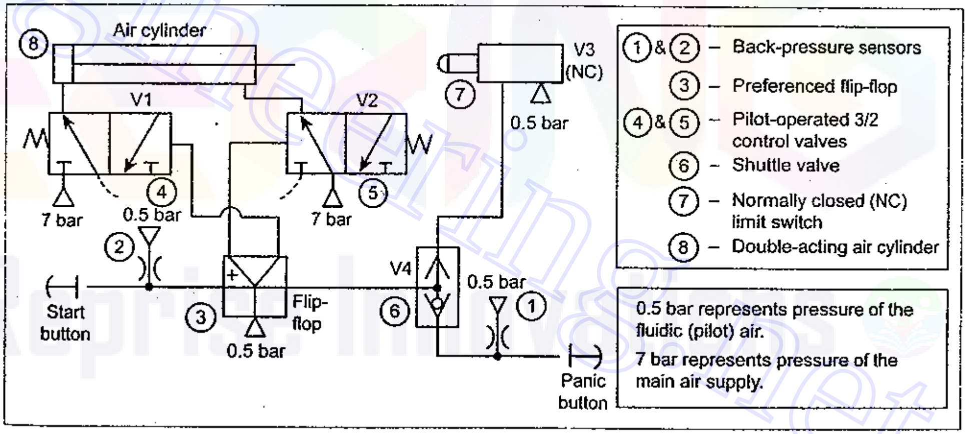

⑧
Air cylinder
V3
(NC)
⑦
0.5 bar
V1
V2
7 bar
④
0.5 bar
7 bar
⑤
②
Start
button
③
+
Flip-
flop
0.5 bar
V4
⑥
0.5 bar
①
Panic
button
① & ② – Back-pressure sensors
③ – Preferenced flip-flop
④ & ⑤ – Pilot-operated 3/2 control valves
⑥ – Shuttle valve
⑦ – Normally closed (NC) limit switch
⑧ – Double-acting air cylinder
0.5 bar represents pressure of the fluidic (pilot) air.
7 bar represents pressure of the main air supply.

Fig. 15.14. Control of air cylinder using preferenced flip-flop

15.6.1.2. Operation

The start and panic buttons represent back-pressure sensors to allow 0.5 bar nozzle-restricted air supplies to activate the control ports of the preferenced flip-flop. The operation of this circuits is as follows :

1. When the START button is pressed momentarily, the preferenced flip-flop actuates the interface 3/2 control valve V1 using 0.5 bar fluidic (pilot) air.
2. Now the 3/2 control valve V1 allows the main supply, air (having 7 bar pressure) to the blind end of the air cylinder and thus the cylinder extends.
3. When the cylinder reaches its maximum stroke, the normally closed (NC) limit switch V3 is actuated. This limit switch V3 now supplies 0.5 bar pilot air through the shuttle valve V4 to switch the flip-flop.
4. When the flip-flop is switched, the pilot air actuates the interface 3/2 control valve V2.
5. Now the 3/2 control valve V2 allows the main supply air (having 7 bar pressure) to the rod end of the air cylinder and thus the cylinder retracts.
6. In the circuit, the panic button is used to override the air limit switch. For instance, if the panic button is momentarily pressed while the cylinder is extending, it will cause the cylinder to retract instantly.
7. The flip-flop with a start-up preference is used to prevent the cycle from starting automatically as soon as the fluidic and pneumatic air supplies are turned on.

15.6.2. Fluidic Sequencing Control of Two Pneumatic Cylinders

15.6.2.1. Circuit

Fig.15.15 illustrates a fluidic logic circuit that shows the fluidic sequencing control of two pneumatic cylinders. This circuit uses two pilot-operated 4/2 control valves (V1 and V2), a preferenced flip-flop, an OR/NOR gate, two normally closed (NC) air limit switches (V3 and V4), and two pneumatic cylinders.

15.6.2.2. Operation

Let us consider the following sequencing of operations: (*i*) Cylinder 1 extends, (*ii*) Cylinder 2 extends, and (*iii*) Cylinders 1 and 2 retract together.

Assume that initially both cylinders are in fully retracted position. The operation of this sequencing circuit is as follows :

1. When the push button is pressed momentarily, the preferenced flip-flop (using 0.5 bar air) pilot-actuates interface 4/2 control valve V1 to extend the cylinder 1 with 7 bar air.
2. When the cylinder 1 is extended fully, the normally closed (NC) limit switch V3 is actuated. Now V3 supplies 0.5 bar pilot signal through the OR/NOR gate to actuate the interface 4/2 control valve V2. Now the cylinder 2 extends.
3. When both cylinders are extended fully, both limit switches V3 and V4 are actuated. Now V4 supplies 0.5 bar pilot signal through the flip-flop to shift the interface 4/2 control valve V1. Now the 7 bar main air from the V1 flows into the rod end of the cylinder 1 and thus cylinder 1 retracts. At the same time, V3 supplies 0.5 bar pilot signal through the OR/NOR gate to shift the interface 4/2 control valve V2. Now the 7 bar main air from the V2 flows into the rod end of the cylinder 2 and thus the cylinder 2 retracts. Thus both cylinders retract together at the same time.

4. The cycle can be repeated by momentarily pressing the push button each time.

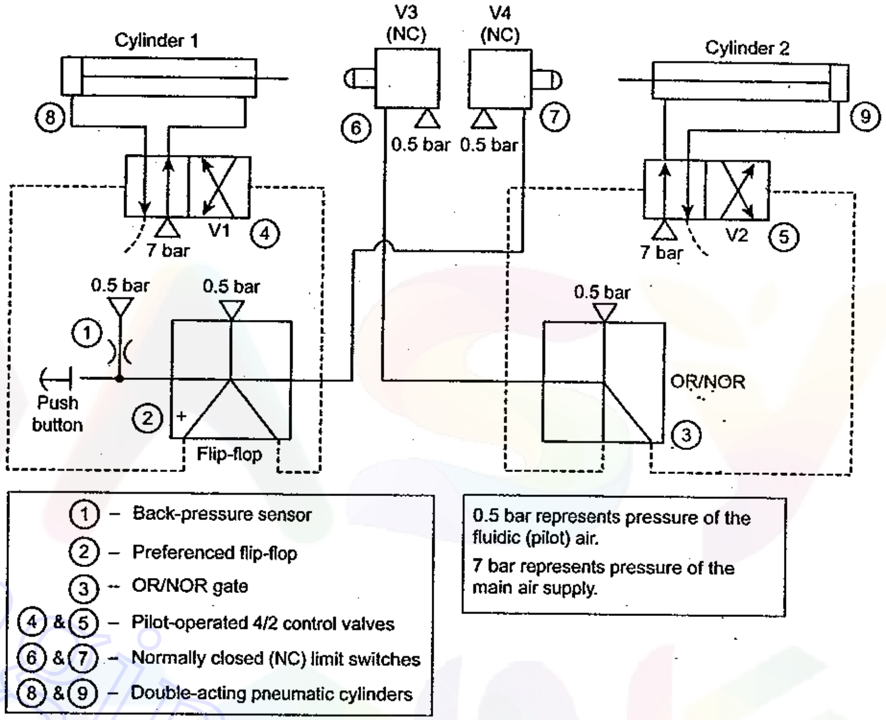

Cylinder 1
V3 (NC)
V4 (NC)
Cylinder 2
8
6
7
9
0.5 bar
0.5 bar
V1
4
7 bar
V2
5
7 bar
0.5 bar
0.5 bar
0.5 bar
1
Push button
2
+
Flip-flop
OR/NOR
3
① – Back-pressure sensor
② – Preferenced flip-flop
③ – OR/NOR gate
④ & ⑤ – Pilot-operated 4/2 control valves
⑥ & ⑦ – Normally closed (NC) limit switches
⑧ & ⑨ – Double-acting pneumatic cylinders
0.5 bar represents pressure of the fluidic (pilot) air.
7 bar represents pressure of the main air supply.

Fig. 15.15. Fluidic sequencing control of two pneumatic cylinders

15.6.3. Continuous Reciprocation of Hydraulic Cylinder Using Fluidic Control

15.6.3.1. Circuit

Fig.15.16 illustrates a fluidic logic circuit that controls the continuous reciprocation of a double-rod ended hydraulic cylinder. This circuit uses two NOR gates, two interruptible jet sensors, a pilot-actuated 4/3 interface valve, a preferenced flip-flop, a selector switch, and the hydraulic cylinder.

15.6.3.2. Operation

The operation of this circuit is as follows :

1. When the selector switch is turned into the ON position, the preferenced flip-flop (using 0.5 bar pilot air) shifts the 4/3 interface valve to its right envelope flow path configuration. Now the 4/3 interface valve allows the oil (having 700 bar pressure) to the hydraulic cylinder. Thus the cylinder moves towards right until the cylinder interrupts the interruptible jet sensor S1.

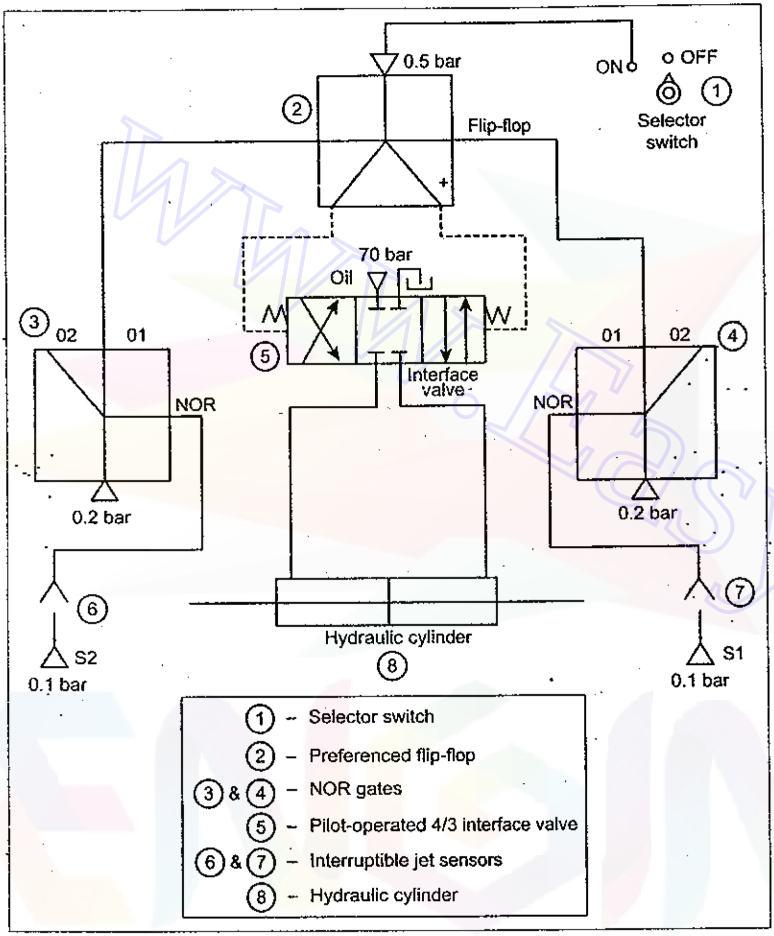


Fig. 15.16. Continuous reciprocation of a hydraulic cylinder using fluidic controls

2. The interruptible jet sensor S1 causes the right side NOR gate to switch to output O1 to switch the flip-flop. Now the flip-flop shifts the 4/3 interface valve to its left envelope flow path configuration, to cause the cylinder to move towards left. When the cylinder rod on the right end retracts out of the sensor S1, the right side NOR gate switches back to output O2. But the flip-flop is not switched because it possesses memory.
3. When the cylinder rod on the left end of the cylinder interrupts the interruptible jet of sensor S2, the left side NOR gate switches to output O1. This again shifts the flip-flop output to the right mode of the 4/3 interface valve. Thus the cylinder moves again towards right.

4. When the selector switch is turned into the OFF position, the 4/3 interface valve is shifted to its spring-centered position. Because there is no output from the flip-flop to pilot the interface valve. In this centre position of the interface valve, the cylinder is hydraulically locked.

   Thus the cylinder reciprocates continuously until the selector switch is turned into the OFF position.

Note The readers can remind themselves that the electrohydraulic and electropneumatic logic circuits have been discussed already in Chapter 13. Unlike fluidic logic circuits, the electrohydraulic and electropneumatic logic circuits use electrical control devices such as push-button switches, limit switches, solenoids, relays, *etc.* Also the concept and applications of ladder diagrams are covered in the same Chapter 9.

MOVING-PART LOGIC (MPL) CONTROL SYSTEMS

15.7. MOVING-PART LOGIC (MPL) CONTROL SYSTEMS

15.7.1. What are Moving-Part Logic Devices

- ✓ Moving-part logic (MPL) devices are miniature valve-type devices that perform switching operations in fluid logic systems by the action of internal moving parts.
- ✓ MPL devices are typically available as spool, poppet, and diaphragm valves.
- ✓ These MPL devices can be actuated by means of mechanical displacement, electric voltage, or fluid pressure.
- ✓ These are miniature-sized valves similar in construction to that of all other pneumatic valves except that they are small and occupy less space.

15.7.2. Advantages of MPL Control System

The advantages of MPL control systems over the other control systems are given below :

1. Very small in size and hence occupies less space.
2. Very fast response time.
3. Comparatively low power consumption.
4. Longer life of elements.
5. Can be readily interfaced with electric and electronic circuits.

15.7.3. Applications of MPL Devices

The MPL devices are well suited for a wide range of applications in biomedical, environmental test equipment, textile machines, packaging machinery, computerized industrial automation, and portable systems.

PROGRAMMABLE LOGIC CONTROL SYSTEM

15.8. PLC APPLICATIONS IN FLUID POWER CONTROL

15.8.1. Introduction

Programmable logic controller (PLC) is one of the important micro-processor based controller. As we aware, microprocessor has a tremendous impact on industrial control and instrumentation due to its high reliability and flexibility at the design and implementation stages. The decreasing cost of microprocessors with increasing facilities in them are acting as catalyst in their widening scope of applications. In recent years, PLCs are being used in place of electro-mechanical relays or cam-operated logic controllers to control fluid power systems.

15.8.2. What is a Programmable Logic Controller (PLC) ?

- ✓ ***Definition :*** *A programmable logic controller (PLC) can be defined as a digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic in order to control machines and processes.*
- ✓ In simple terms, a PLC is a user-friendly electronic computer designed to perform logic functions such as AND, OR, and NOT for controlling the operation of industrial equipment and processes.
- ✓ Thus a PLC consists of solid-state digital logic elements for making logic decisions and providing corresponding outputs.
- ✓ Basically, PLCs are designed as a replacement for hard-wired electro-mechanical relays to control fluid power systems.

15.8.3. PLCs Vs Computers

PLCs are similar to general-purpose computers. But PLCs have certain features which are specific to their use as controllers. Some of the important features of PLCs are :

1. PLCs are rugged and designed to withstand vibrations, temperature, humidity, and noise.
2. The interfacing for inputs and outputs is inside the controller.
3. They are easily programmed and have an easily understood programming language. Programming is primarily concerned with logic and switching operations.

15.8.4. Advantages of PLCs over Electromechanical Relays

The PLCs replace electromechanical relays due to their following advantages :

1. PLCs are more reliable and faster in operation.
2. They are smaller in size and can be more readily expanded.
3. They require less electrical power.

4. They are less expensive when compared to electromechanical relays for the same number of control functions.
5. Hard-wired electromechanical relays lack flexibility. For instance, when system operation requirements change, then the relays have to be rewired.
6. PLCs have very few hardware failure when compared to electro-mechanical relays.
7. Special functions such as time-delay actions and counters, can be easily performed using PLCs.

15.9. MAJOR UNITS OF A PLC

A PLC consists of the three major elements, as shown in Fig.15.17. They are :

1. Central processing unit (CPU),
2. Programmer/monitor (PM), and
3. Input/output module (I/O).

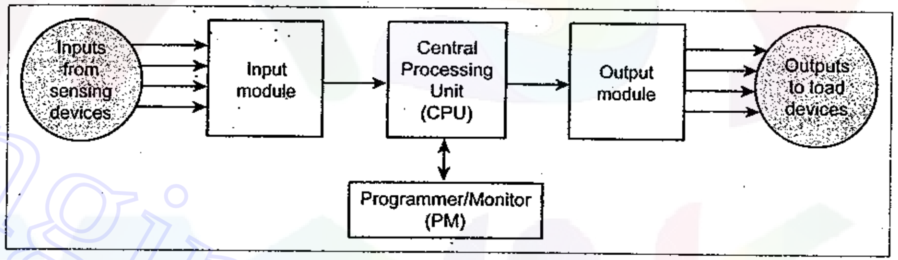


Fig. 15.17. Block diagram of a PLC

15.9.1. Central Processing Unit (CPU)

- ✓ The CPU controls and processes all the operations within the PLC, that's why this unit is referred as the 'brain' of the PLC.
- ✓ ***Function :*** The CPU (*i*) receives input data from various sensing devices such as switches, (*ii*) executes the stored program, and (*iii*) delivers corresponding output signals to various load control devices such as relay coils and solenoids.
- ✓ It consists a microprocessor with a fixed memory (ROM-'read only memory') and a variable memory (RAM–'random access memory').

15.9.2. Programmer/Monitor (PM)

- ✓ The programmer/monitor unit allows the user to enter the desired programme into the RAM.
- ✓ The programme which is entered in relay logic (in RAM) determines the sequence of operation of the system to be controlled.

15.9.3. Input/Output Module (I/O)

- ✓ This module interfaces between the fluid power system input sensing and output load devices and the CPU.
- ✓ ***Function :*** The purpose of the I/O module is to transform the various signals received from or sent to the fluid power interface devices (such as push-button switches, pressure switches, limit switches, solenoid coils, motor relay coils, and indicator lights).

15.10. PROGRAMMING THE PLC

15.10.1. What is mean by Ladder Programming ?

- ✓ The basic form of programming commonly used with PLCs is *ladder programming.*
- ✓ PLC programming based on the use of ladder diagrams involves writing a program in a similar manner to drawing a switching circuit.
- ✓ The ladder diagram consists of two vertical lines representing the power lines. Circuits are connected as horizontal lines. *i.e.*, the rungs of the ladder, between these two verticals.

15.10.2. PLC Ladder Symbols

- ✓ Fig.15.18 shows the basic standard symbols that are used.
- ✓ Fig.15.19 shows an example of rungs in a ladder diagram.

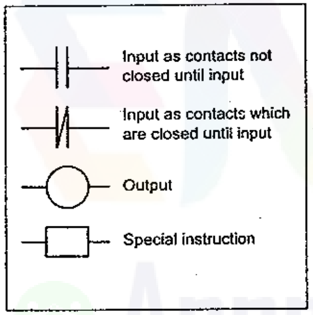

Input as contacts not closed until input
Input as contacts which are closed until input
Output
Special instruction

Fig. 15.18. Symbol

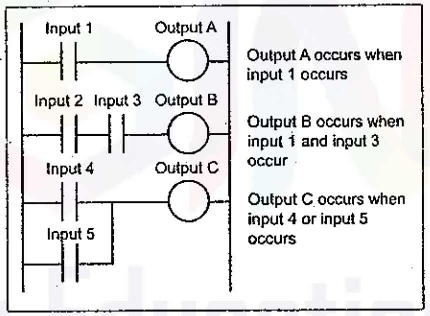

Input 1
Output A
Output A occurs when input 1 occurs
Input 2
Input 3
Output B
Output B occurs when input 1 and input 3 occur
Input 4
Output C
Output C occurs when input 4 or input 5 occurs
Input 5

Fig. 15.19. Example of rungs in a ladder diagram

15.10.3. Construction

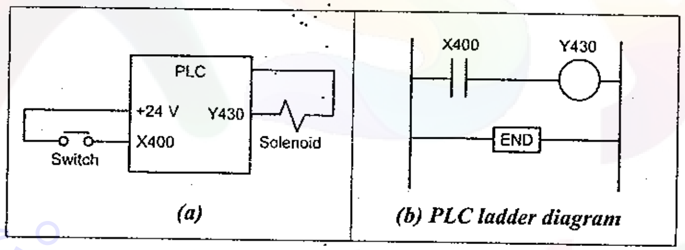
In drawing the circuit line for a rung, inputs must always precede outputs and there must be at least one output on each line. Each rung start with an input or a series of inputs and end with an output.

The inputs and outputs are numbered, the notation used depending on the manufacturer. For example, the Mitsubishi F series of PLCs precedes input elements by an X and output elements by a Y and uses the following numbers :

Inputs	X400–407, 410–413
	X500–507, 510–513
	(24 possible inputs)
Outputs	Y430–437
	Y530–537
	(16 possible outputs)

15.10.4. Illustration of Drawing a PLC Ladder Diagram

Consider an example of a solenoid valve which opens to allow water to enter a vessel. This situation, where the output from the PLC is to energise a solenoid when a normally open start switch connected to the input is being closed, is shown in Fig.15.20(*a*). The PLC ladder diagram for the situation is shown in Fig.15.20(*b*).



(a) *(b) PLC ladder diagram*

Fig. 15.20. Illustration of drawing a PLC ladder diagram

Starting with the input, we have the normally open symbol | |. This might have an input address X400. The line terminates with the output, the solenoid, with the symbol O. This might have the output address Y430. To indicate the end of the program the end rung is marked. When the switch is closed the solenoid is activated.

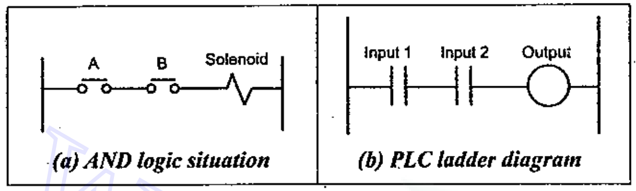
15.11. PLC LADDER PROGRAMS FOR LOGIC FUNCTIONS

The logic functions (such as AND, OR, NOR, *etc.*) can be obtained by combinations of switches (such as limit switches, solenoid coils, *etc.*). The following sections show how we can write PLC ladder programs for such combinations.

15.11.1. AND Logic Function

Fig.15.21(*a*) shows a situation where a coil is not energized unless two, normally open, switches are both closed. Switch A and switch B have both to be closed, which thus gives an AND logic situation.

Fig.15.21(*b*) shows the PLC ladder diagram for the AND logic function shown in Fig.15.21(*a*). In Fig.15.21(*b*), the ladder diagram starts with | |, labelled Input 1, to represent switch A and in series with it | |, labelled Input 2, to represent switch B. The line then terminates with O to represent the output.

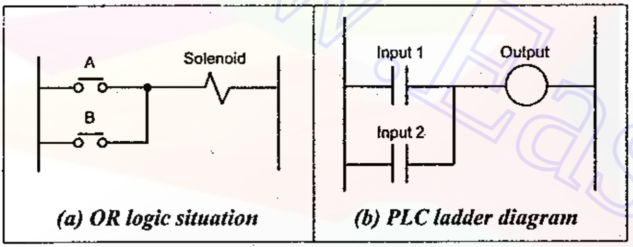


(a) AND logic situation (b) PLC ladder diagram

Fig. 15.21. An AND system

15.11.2. OR Logic Function

Fig.15.22(*a*) shows a situation where a coil is not energized until either, normally open, switch A or B is closed. This situation is an OR logic gate.



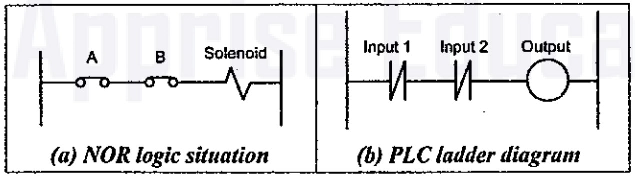
(a) OR logic situation (b) PLC ladder diagram

Fig. 15.22. An OR system

Fig.15.22(*b*) shows the PLC ladder diagram for the OR logic gate shown in Fig.15.22(*a*). In Fig.15.22(*b*), the ladder diagram starts with | |, labelled Input 1, to represent A and in parallel with it | |, labelled Input 2, to represent switch B. The line then terminates with O to represent the output.

15.11.3. NOR Logic Function

Fig.15.23(*a*) shows a NOR logic gate situation. Fig.15.23(*b*) shows the PLC ladder program for the NOR gate shown in Fig.15.23(*a*). Since there has to be an output when neither A nor B have an input and when there is an input to A or B the output stops, the ladder program shows Input 1 in parallel with Input 2, with both being represented by normally closed contacts.

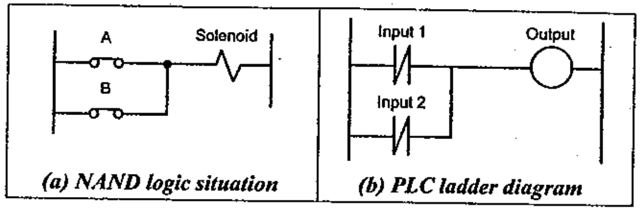


(a) NOR logic situation (b) PLC ladder diagram

Fig. 15.23. A NOR system

15.11.4. NAND Logic Function

Fig.15.24(*a*) shows a NAND logic gate situation. Fig.15.24(*b*) shows the PLC ladder program for the NAND gate shown in Fig.15.24(*a*). There is no output when both A and B have an input. Thus for the ladder program line to obtain we require no inputs to Input 1 and to Input 2.



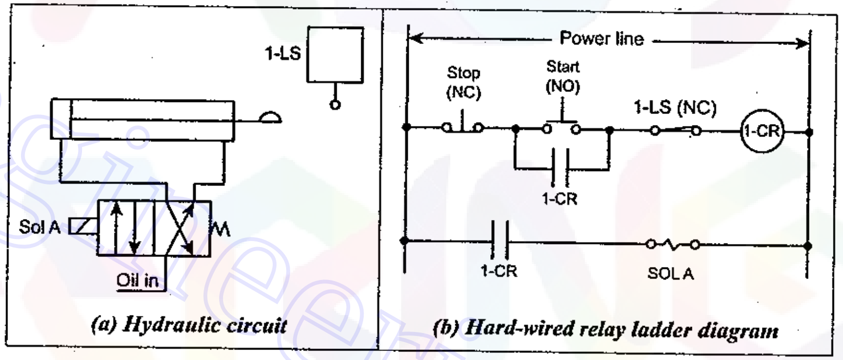
(a) NAND logic situation (b) PLC ladder diagram

Fig. 15.24. A NAND system

15.12. PLC CONTROL OF A HYDRAULIC CYLINDER

15.12.1. Circuit and Relay Ladder Diagram

Consider a system, shown in Fig.15.25, which is used to control a double-acting hydraulic cylinder using a single limit switch. Fig.15.25(*b*) shows the hard-wired relay ladder diagram for system shown in Fig.15.25(*a*).



(a) Hydraulic circuit (b) Hard-wired relay ladder diagram

Fig. 15.25. Control of a hydraulic cylinder using a single limit switch

15.12.2. PLC Ladder Logic Diagram

Fig.15.26 shows a PLC ladder logic diagram for the equivalent hard-wired relay ladder diagram shown in Fig.15.25(*b*). It may be noted that the layout of both diagrams are similar. The two rungs of the relay ladder diagram are converted to two rungs of the PLC ladder logic diagram.

Since the input modules act like relays, the relay contacts are substituted for original switch contacts (with the prefix X followed by a number) and output modules are substituted by relay coils (with the prefix Y followed by a number).

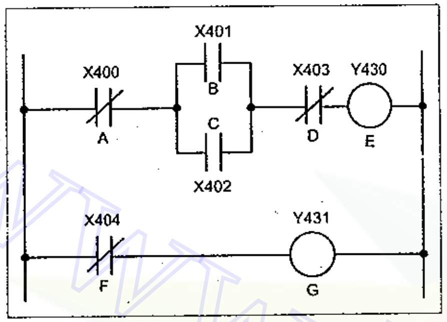


Fig. 15.26. PLC ladder logic diagrams

15.12.3. Boolean Equations

We know that the PLC performs operations based on logic functions. Each rung of a ladder diagram be represented by a Boolean equation. For this purpose, the capital letters A, B, C, *etc.* are used to represent each electrical component in the Fig.15.36. Now the Boolean equations can be written for each rung as follows :

Top Rung : $\bar{A} \cdot (B + C) \cdot \bar{D} = E$

This equation can be read as : NOT A AND (B OR C) AND NOT D EQUALS E. We know that OFF state can be represented by 0 and ON state by 1. This equation means that E is energized when A is NOT actuated AND B OR C is actuated AND D is NOT actuated.

Bottom rung : F = G

This means that G is energized when F is actuated.

REVIEW AND SUMMARY

✓ *At the beginning of this chapter, the technology of fluidics and how fluidics is used to control fluid power systems have been discussed.*

✓ ***Fluidics*** *is the technology that utilizes fluid flow phenomena in components and circuits to perform a wide variety of control functions.*

✓ *The fluidic devices control fluid power force components and fluid power master control components by the same media with which the force components are operated—either gases or liquids.*

✓ ***'Coanda effect'*** *: When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the well.*

✓ ***Basic fluidic devices are :***

1. *Basic bistable flip-flop,*
2. *Flip-flop with start-up preference,*
3. *SRT flip-flop,*
4. *OR/NOR gate,*
5. *AND/NAND gate, and*
6. *Exclusive OR gate.*

✓ *The bistable flip-flop device is normally used as a memory device. A flip-flop with start-up preference is used in applications where a specific output is required when the power supply is first turned ON and all controls are OFF. SRT flip-flop is an acronym for SET-RESET-TRIGGER flip-flop. The monostable devices—OR/NOR and AND/NAND gates—are required to perform monostable function which is analogous to spring return function.*

✓ ***Types of fluid sensors are :***

1. *Back-pressure sensor,*
2. *Cone-jet proximity sensor,*
3. *Interruptible-jet sensor, and*
4. *Contact sensing.*

✓ *The construction, operation and symbol of the various fluidic devices and fluid sensors were presented in this chapter.*

✓ ***Moving-part logic (MPL) devices*** *are miniature valve-type devices that perform switching operations in fluid logic systems by the action of internal moving parts.*

✓ ***A programmable logic controller (PLC)*** *can be defined as an digital electronic device that uses a programmable memory to store instructions and to implement functions such as logic, sequencing, timing, counting, and arithmetic in order to control machines and processes.*

✓ ***Major units of a PLC are :***

1. *Central processing unit (CPU),*
2. *Programmer/monitor (PM), and*
3. *Input/output module (I/O).*

✓ *At the end of the chapter, a brief note on PLC applications in fluid power control has been presented.*

✓ *The basic form of programming commonly used with PLCs is ladder programming.*

KEY TERMS ONE SHOULD REMEMBER

Fluidics
Coanda effect
Wall-attachment effect
Fluidic devices
  Bistable flip-flop
  Start-up preference flip-flop
  SRT flip-flop
  OR/NOR gate
  AND/NAND gate
  Exclusive OR gate
Truth table
Monostable devices
Boolean algebra
Fluid sensors
  Back-pressure sensor
  Cone-jet proximity sensor
  Interruptible-jet sensor
  Contact sensing
Pneumatic logic circuits
Fluidic sequencing control
Moving-part logic (MPL) devices
Programmable logic controller (PLC)
Electromechanical relays
Central processing unit (CPU)
Programmer/Monitor (PM)
Input/Output module (I/O)
Ladder programming
PLC ladder symbols
PLC ladder logic diagrams

REVIEW QUESTIONS

Short Answer Type Questions

On Fluidics

1. What is fluidics ?
2. What advantages does fluidics offer ?
3. At what pressures do fluidic devices function ?
4. Where are fluidic control systems preferred than other control systems ?
5. State the 'Coanda effect'.
6. What is a bistable flip-flop ?
7. What are monostable devices ?
8. When do you use a flip-flop with start-up preference ?
9. What is the use of truth table in logic devices ?
10. What do you mean by SRT flip-flop ?
11. With the symbol, give the truth table for fluidic OR/NOR gate.
12. Give the symbol and truth table for fluidic AND/NAND gate.
13. What is the difference between an OR gate and an EXCLUSIVE-OR gate ?
14. What is 'Boolean algebra' ? Write its two functions relative to fluid power systems.
15. What are fluid sensors ?
16. Name four fluid sensors that are used in fluid power systems.
17. What is meant by the term 'contact sensing' ?

On MPL Control Systems

18. What are moving-part logic devices ?
19. Name three ways in which MPL devices can be actuated.
20. What are the distinctive features that differentiates MPL devices from fluidic devices.
21. Name few applications of MPL devices.

On PLC Systems

22. What is a PLC ?
23. How does a PLC differ from a general-purpose computer ?
24. List any four advantages that PLCs provide over electromechanical relay control systems.
25. List three major units of a PLC.
26. What is the function of the CPU in a PLC ?
27. What is the purpose of the I/O module in a PLC ?

Essay Answer Type Questions

1. What is wall-attachment theory as applied in fluidics ? Also illustrate the 'wall-attachment' phenomenon ?
2. (*a*) What is a SRT flip-flop ? Explain how it works.

   (*b*) How does a start-up preference flip-flop differ in operation from a bistable flip-flop ?
   (*c*) What is the difference between a monostable and bistable device ? Explain the operation of any one monostable device.
3. (*a*) How does a back-pressure sensor differ in operation from a proximity sensor ?
   (*b*) Explain the working of an interruptible-jet sensor.
   (*c*) What is meant by contact sensing ? Explain how it senses an object.
4. With a neat fluidic logic circuit, explain how the control of air cylinder can be achieved using preferenced flip-flop.
5. Explain the fluidic sequencing control of two pneumatic cylinders with the help of a fluidic logic circuit.
6. Illustrate a fluidic logic circuit that controls the continuous reciprocation of a double-rod-ended hydraulic cylinders.
7. With a block diagram, describe the operation of a programmable logic controller.
8. Draw the PLC ladder diagram for the following logic functions :
   (*i*) AND, (*ii*) OR, (*iii*) NOR, and (*iv*) NAND.
9. Explain the PLC of a hydraulic cylinder, by constructing a PLC ladder logic diagram.

□□

Chapter 16

Fluid Power Circuits: Failure and Troubleshooting

"The trouble with meet of us is that we would rather be ruined by praise than saved by criticism."

–Norman Vincent Peale

"I had six honest serving men – They taught me all I knew: Their names were Where and What and When and Why and How and Who."

– Rudyard Kipling

"'Knowledge, without common sense', says Lee 'is folly; without method, it is waste; without kindness, it is fanaticism; without religion, it is death'. But with common sense, it is wisdom; with method, it is power; with charity, it is beneficience; with religion it is virtue, and life, and peace."

– Farrar

Learning Objectives

While reading and after studying this chapter, you will be able to:

☑ Identify the most common faults and their common causes in hydraulic systems.

☑ Understand the significance of troubleshooting in fluid power circuits.

☑ Use tree-branching charts to quickly find faults in hydraulic and pneumatic systems.

☑ Tabulate the various faults, probable causes, and their remedies of a hydraulic system and its components.

☑ Tabulate the various faults, probable causes, and their remedies of a pneumatic system and its components.

CHAPTER 16 FLUID POWER CIRCUITS: FAILURE AND TROUBLESHOOTING

16.1. INTRODUCTION

The new applications of hydraulic and pneumatic power systems are being found and adopted every day in all fields. Also fluid power is considered as the muscle of automation because the future automated industries will largely depend on fluid power for their operations. So we cannot afford the failure of these systems. Like any other systems, fluid power systems also develop various types of faults and defects which need periodic and routine maintenance. Therefore in order to enhance the operational reliability and maintainability of the fluid power system, it is highly required to take up various maintenance and repair measures to prevent failure of components and stoppage of the system.

It is also found that the maximum trouble-free life of the fluid power systems mainly depend on the following four basic requirements :

1. Properly installed equipments,
2. Properly trained personnel,
3. Planned preventive maintenance, and
4. Efficient troubleshooting.

In this chapter, we shall describe how to troubleshoot fluid power circuits effectively, depending on the symptoms of the problem involved.

FAILURE AND TROUBLESHOOTING OF HYDRAULIC SYSTEM

16.2. FAILURE AND TROUBLESHOOTING OF HYDRAULIC SYSTEM

16.2.1. Common Faults in Hydraulic Systems

Table 16.1 lists the most common type of defects that can be found in hydraulic systems.

Table 16.1. Common faults in hydraulic systems

1.	Reduced speed of travel of machine tool elements.
2.	Slow response to control.
3.	Excessive loss of system pressure.
4.	Excessive leakage in the system.
5.	Rise in the oil temperature.
6.	Non-uniform or jerky movement of tables, carriages, *etc.*, especially at low feed rates.

7. Increased noise in the system.
8. No supply or less supply from pump.
9. Cavitation of seal failure.
10. High rate of seal failure.
11. Poor oil life.
12. High degree of contamination level of system medium.

16.2.2. Common Causes of Hydraulic System Breakdown

Table 16.2 lists the most common causes of hydraulic system breakdown.

Table 16.2. Common causes of hydraulic system breakdown

1. Inadequate supply of oil in the reservoir.
2. Clogged or dirty oil filters.
3. Leaking seals.
4. Loose inlet lines that cause the pump to take in air.
5. Incorrect type of oil.
6. Excessive oil temperature.
7. Excessive oil pressure.

16.2.3. Fault Finding Using Troubleshooting Charts

The term troubleshooting refers to an organised and systematic study of the problem and a logical approach to the difficulty faced in a system.

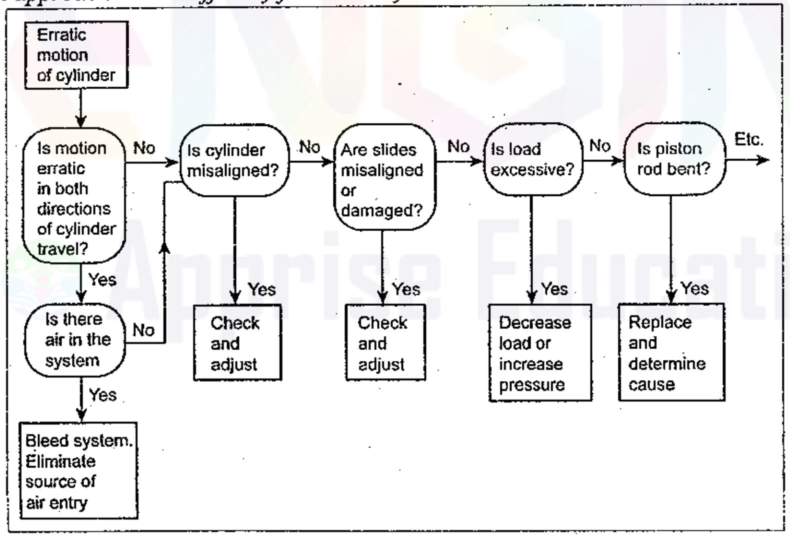

Erratic motion of cylinder
Is motion erratic in both directions of cylinder travel?
No
Is cylinder misaligned?
No
Are slides misaligned or damaged?
No
Is load excessive?
No
Is piston rod bent?
Etc.
Yes
Yes
Check and adjust
Yes
Check and adjust
Yes
Decrease load or increase pressure
Yes
Replace and determine cause
Is there air in the system
No
Yes
Bleed system. Eliminate source of air entry

Fig. 16.1. Tree-branching chart for a hydraulic system

Maintenance engineers often use a fault finding chart, also known as ***tree-branching chart***, to simplify the complex fault finding process in a hydraulic circuit. A typical tree-branching chart is illustrated in Fig.16.1.

As could be seen from the chart, it asks a question which has answers only in the 'yes' or 'no' type. This answer will determine the next step to be taken. Thus, this tree-branching chart technique helps the maintenance personnel in developing a logical and rapid approach to fault diagnosis.

16.2.4. Fault Diagnosis of Hydraulic System

Table 16.3 presents the various faults, their symptoms, probable causes, and also the remedial actions that can be taken to prevent them in hydraulic systems.

Table 16.3. Various faults, possible causes and remedies of a hydraulic system and its components

Trouble/Fault	Probable causes	Remedial actions
I. PUMP		
1. Pump delivering insufficient or no oil	Wrong direction of shaft	Must be reversed immediately to prevent seizure and breakage of parts due to lack of oil
	Pump shaft turning too slowly to prime itself	Check minimum speed recommendation and momentarily increase rpm, to rectify
	Clogged strainer or suction pipe line	Clean strainer or suction pipe line. Remove foreign matter
	Strainer capacity insufficient	Replace with a strainer whose capacity is more than twice the maximum flow rate
	Air leak in suction line	Add oil and check oil level in reservoir. Check for leaks and repair
	Faulty rotating part in the pump body	Check by listening to the sound. Remove the cover and check the internal mechanism. Replace, if necessary
	Oil leak in pump casing due to seizure or wear of pump sliding parts	Check the sliding parts
	Low level of oil in the reservoir	Add the oil recommended as per the indicator line
	Oil viscosity too heavy to pick up prime or too light causing excessive slippage	Use oil as per recommendation

Trouble/Fault	Probable causes	Remedial actions
2. Pump developing unstable or zero pressure	Pump not delivering oil for any of the above reasons	Apply the above remedies
	Relief valve setting not high enough	Correct valve setting by using pressure gauge
	Relief valve sticking open	Check relief valve. If necessary, dismantle and clean valve
	Clogged orifice of the relief valve	Overhaul and clean relief valve
	Mis-assembly, mis-connection or mis-operation of various valves in the circuit	Must be corrected
	Faulty performance of various valves or excessive oil leakages in the circuit through actuators and valves *etc.*	Test each component separately and repair
	Faulty pressure gauge	Check and replace if necessary
	Partially clogged suction line or suction strainer	Clean and remove foreign matter
3. Pump making noise	Misalignment of pump and prime mover	Check and rectify
	Strainer capacity insufficient	Replace with a strainer whose capacity is more than twice the maximum flow rate
	Air leak at pump's suction pipe joints or from shaft packing of the pump	Pour oil on suspected joints while listening for change in sound. If sound stops, tighten the joint
	Air remains in pump casing	Eliminate air through the air breather
	Small size of suction pipe	Replace so that the flow velocity on the suction side will be approximately 0.5 to 1 m/s
	Coupling misalignment	Re-align properly
	Pump bolts very loose	Tighten
	Resonance noises in the system	Reinforce by installing supports to eliminate resonance
	Air bubble or too much foam in suction oil.	Check to be certain that the return lines are below oil level and well separated from suction lines.
	Very high viscosity.	Use recommended oil.
	Pump running too fast.	Check the recommended maximum speed.
4. Pump oil over-heated	Faulty oil cooler	Repair
	Insufficient size of oil reservoir	Increase capacity or install an oil cooler
	Pump pressure too high	Readjust relief valve setting
	Excessive flow velocity	Replace piping
	Seizure of pump's sliding parts	Dis-assemble and repair. Check for foreign matter in oil and see if the pump casing is filled with oil
5. Internal leakage around pump	Shaft packing worn out	Replace
	Top cover packing damaged	Change the packing and apply clamping torque on the cover as per manufacturer's recommendation
6. Excessive wear	Abrasive matter in the hydraulic oil being circulated through	Install an adequate filter or replace oil more often
	Viscosity of oil very low at working conditions	Check pump manufacturer's recommendations or consult your hydraulic engineer
	Sustained high pressure above the maximum pump rating	Check maximum setting of the relief valve
	Misaligned drive or tight belt drive	Check and rectify
	Air recirculation causing chatter in the system	Remove air from the system
7. Breakage of parts inside pump housing	Excessive pressure above maximum pump rating	Adjust relief valve properly
	Seizure due to lack of oil	Check oil level in reservoir and cleanness of strainer and any other possible restrictions in suction lines
	Solid matter wedged in the pump	Install a filter in the system. Clean suction strainer more often
	Excessive tightness of head screws	Follow manufacturer's recommendations
II. RELIEF VALVES		
1. Erratic pressure	Dirt in oil	Clean strainer and flush the system
	Worn poppet or seat	Lap the poppet or replace
	Piston sticking in the main body	Check and rectify

Trouble/Fault	Probable causes	Remedial actions
2. No or low pressure	Vent connection open	Check and rectify
	Balance hole plugged	Check and rectify
	Poppet not seating properly	Check, lap and repair
3. Excessive noise or chatter	High oil velocity	Check and rectify
	Faulty or worn poppet or seat	Check, lap or replace
	Excessive tank line pressure	Check and rectify
	Long vent line or pressure setting too close to that of another valve in the circuit	Check and rectify
	Valve setting too close to the system operating pressure	Set relief valve at least 10 bar higher than the required working pressure of the system
III. DIRECTIONAL CONTROL VALVES (DCVs)		
1. Faulty or incomplete shifting	Worn out control linkage, shift pin, *etc.*	Check and repair
	Insufficient pilot pressure	Check and rectify
	Burned out solenoid	Check and replace
	Worn spring centering mechanism	Check and replace
2. Cylinder creeping or drifting	Valve spool not centering properly	Check and rectify
	Valve spool not shifting completely	Check and replace
	Valve spool or body worn out	Check and rectify
	Leakage past the piston in the cylinder	Check and overhaul the cylinder
IV. SEQUENCING VALVES		
1. Premature movement of secondary operation	Valve set too low	Check and set it higher
	Excessive load on primary cylinders	Check and adjust accordingly
	High inertia load on primary cylinder	Check and make sequence valve remote controlled
2. No movement or slow secondary operation	Sequence valve setting too high	Check and adjust again
	Relief valve setting too close to that of sequence valve	Should have at least 10 bar differential
	Valve spool binding in body	Check and repair
V. UNLOADING VALVES		
1. Fails to completely unload pump	Valve setting too high	Set correctly
	Remote pressure setting too low	Adjust properly
	Valve spool binding in body	Overhaul valve

Trouble/Fault	Probable causes	Remedial actions
VI. COUNTERBALANCE VALVES		
1. Will not support load	Valve setting too low	Set properly
	Dirt under integral check valve	Flush the system
	Valve spool and body worn out	Replace worn out parts
	Leakage past the piston in the cylinder	Check and overhaul the cylinder
VII. FLOW CONTROL VALVES		
1. Variation in feed	Sticking hydrostat	Overhaul valve
	Cylinder or motor leakage	Overhaul cylinder or motor
	Change in oil viscosity	Check and replace oil
	Improper pressure drop across valve	Adjust correctly
	Inadequate lubrication of machine parts	Check and do the necessary rectifications
VIII. REMOTE FLOW CONTROL VALVES		
1. External leakage	Back pressure in drain line or defective seals	Drain directly to reservoir or replace seals
2. Feed rate variation	Hydrostatic pressure compensator inoperative or sticking hydrostat	Clean valve and flush system. Polish hydrostat and metering spool. Replace defective seals
3. Maximum flow not obtainable	Contaminants in the throttling orifice. Metering spool binding or not shifting fully. Insufficient voltage in torque motor	Clean valve. Check torque motor coils and input current. Re-align properly
4. Check valve-inoperative	Dirt lodged between the mating faces or finished faces	Disassemble and flush thoroughly
IX. HYDRAULIC MOTORS		
1. Motor turning in wrong direction	Incorrect piping between control valve and fluid motor	Check circuits to determine correct piping
2. Absence of proper speed and torque	System overload, relief valve adjustment not set high enough	Check required system pressure and reset relief valve
	Relief valve sticking open	Inspect and overhaul relief valve, set correctly
	Free recirculation of oil to reservoir	Identify the exact point of fault and rectify
	Driven mechanism binding, because of mis-alignment	Remove fluid motor and check the torque required for drive shaft
	Pump not delivering sufficient volume or pressure	Check pump delivery and pressure

Trouble/Fault	Probable causes	Remedial actions
3. External oil leakage from fluid motor	Gasket leaking (may be due to drain not connected to the reservoir when required)	Replace gasket. If drain line is required, it must be connected directly to reservoir.
4. Times of operation longer than specified	Air in system	Bleed
	Internal leakage in actuating cylinder or directional valve	Repair and replace worn out parts
	Worn out pump	Repair
	Action is sluggish only on startup and becomes alright after warming up and vice-versa	It is due to wrong selection of hydraulic oil. Consult manufacturer's recommendations for correct hydraulic oil viscosity
	Low auxiliary control pressure	Control lines may be too small particularly if they are very long
X. HYDRAULIC CYLINDERS		
1. Piston packing failing too often	Defective or poor quality of packing	Check and consult a hydraulic engineer for the correct solution
	Packing retainer bent	Check and rectify
	Piston bearing worn out	Check and replace
	Cylinder wall surface excessively worn out or badly scored	Check, smoothen and replace if necessary
	Getting damaged during assembling	Check and take care during assembling
	Packing might be facing very high pressures.	Adjust relief valve correctly
	Too much contaminants in the hydraulic oil	Flush system
	Design defects in mounting	Consult hydraulic engineer
	Defective rod wiper	Check and change rod wiper
2. Reduced speed	Oil bypassing the piston	Check and overhaul cylinder. Replace defective parts
	Wrong setting of the control valve	Adjust properly
	Less delivery from pump	Check and rectify
	Directional valve not shifting fully	Check directional valve as discussed before
	Low setting or any defect in relief valve	Check and correctly set as mentioned before

Trouble/Fault	Probable causes	Remedial actions
3. Insufficient force available or no movement at all	Defective or very low set relief valve	Check and correctly set as mentioned before
	Oil bypassing the piston	Check and overhaul the cylinder
	Pump not delivering oil	Check and overhaul the cylinder
	Defective directional valve (specially solenoid operated or hydraulically operated)	Check and rectify
XI. ACCUMULATORS		
1. Sudden drop of pressure when position of selector valve is changed	Internal or external leak in accumulator	Check and repair leak
2. No pressure available after pump is stopped	Leaking gas valve or leaking check valve in the line	Check and replace valve
3. Sluggish response	Gas pre-charge not sufficient	Pre-charge according to manufacturer's instructions and check for gas leak, if any.
XII. GENERAL CIRCUIT PROBLEMS		
1. Insufficient pressure in system	Very low relief valve setting	Reset
	Leakage of full pump delivery within circuit	Detect and rectify
	Pump slipping its entire volume	Check and repair
2. Slow operations	Leakage through cylinder or fluid motors	Check and repair
	Valve not closing or shifting properly	Check and repair
	Relief valve set at a much higher pressure than necessary. Excess oil dissipated through increased slippage in various parts or through relief valve or through throttle valve	Reset relief valve slightly above the maximum pressure required for the work stroke. Follow manufacturer's recommendations for maximum pressure setting.
	Internal oil leakage due to wear in pump or in other places	Replace or repair pump and rectify other faults after detecting
	Viscosity of oil is very high	Follow manufacturer's recommendations for the correct viscosity grade to be used at various temperatures

Trouble/Fault	Probable causes	Remedial actions
3. Excessive heating of oil in system	Pump assembled too tightly after overhaul. This reduces clearance and increases rubbing friction.	Follow manufacturer's instructions while trying to reassemble
	Leaking check valves and relief valves in the pump	Repair
	Improper functioning of oil cooler or supply of cooling water cut-off	Check and repair
	Automatic unloading control inoperative	Check and repair
	Restricted lines	If lines are crimped, replace. If partially plugged for any reason remove obstruction
	Large pump deliveries not unloaded properly	Study circuits and rectify the fault
	Insufficient radiation	Use artificial cooling
	Reservoir too small to provide adequate cooling	Replace with larger reservoir or install cooler
	Undersized valves or pipings	Check and repair

FAILURE AND TROUBLESHOOTING OF PNEUMATIC SYSTEM

16.3. FAILURE AND TROUBLESHOOTING OF PNEUMATIC SYSTEM

16.3.1. Fault Finding using Troubleshooting Charts

Similar to hydraulic systems, a tree branching chart shown in Fig.16.2 can be used to find the faults in pneumatic systems.

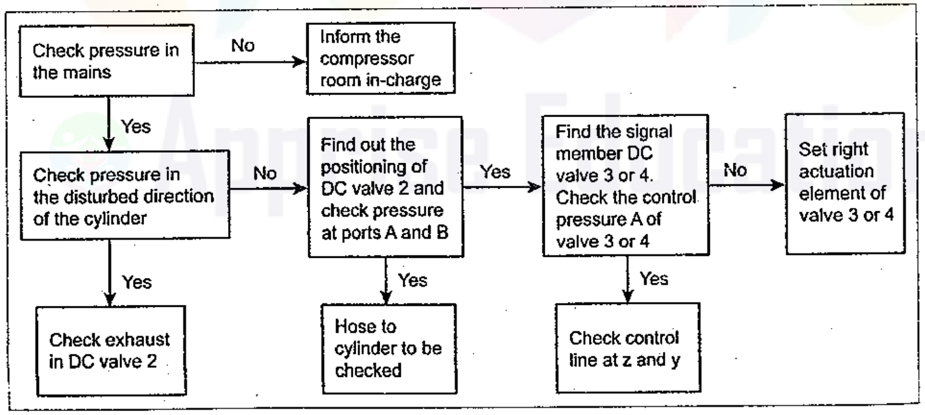

Check pressure in the mains
No
Inform the compressor room in-charge
Yes
Check pressure in the disturbed direction of the cylinder
No
Find out the positioning of DC valve 2 and check pressure at ports A and B
Yes
Find the signal member DC valve 3 or 4. Check the control pressure A of valve 3 or 4
No
Set right actuation element of valve 3 or 4
Yes
Check exhaust in DC valve 2
Yes
Hose to cylinder to be checked
Yes
Check control line at z and y

Fig. 16.2. Tree-branching chart for a pneumatic system

16.3.2. Fault Diagnosis of Pneumatic System

Table 16.4 presents the various faults, their symptoms, probable causes, and also the remedial actions that can be taken to prevent them in pneumatic systems.

Table 16.4. Various faults, possible causes, and remedies of a pneumatic system and its components

Trouble/Fault	Probable causes	Remedial actions
I. COMPRESSORS		
1. Unusual noise	Leaking cylinder valve	Adjust and stop leakage
	Loose belt in compressor wheel, motor pulley	Adjust the belt as recommended
	Motor with excessive end play in shaft	Adjust the end play
	Carbon on top of the piston	De-carbonise
	Leaking, broken or worn out constant speed unloader parts	Adjust or replace
	Valve seats worn	Recondition valve seat
	Worn or scored connecting rod, piston pin or crank pin bearings	Recondition the connecting rod, replace or condition gudgeon pin and crank pin bearings
	Defective ball bearings on crank shaft or on motor shaft	Replace bearings
	Loose motor fan	Tighten the motor fan
	Cylinders or pistons scratched, worn or scored	Rebore cylinder and replace piston
2. Inadequate performance	Dirt in suction filter	Clean filtering plate and filter disc. Do not use gasoline for danger of explosion
	Defective sealing of cylinder head	Mount fresh packing of the cylinder head
	Valve interference through dislocated valve seat and valve guide	Exchange valve insert plate
	Worn out pistons and piston rings as well as worn out cylinder	Exchange piston with rings and also the cylinder if necessary
	Piston rings broken or not sealed	Replace piston rings as per manufacturer's instructions
	End gap not staggered in grooves	Stagger the end gaps, make the rings free in the grooves
	Rough, scratched or excessive end gaps	Replace
	Cylinders or pistons scratched, worn or scored	Replace or repair

Trouble/Fault	Probable causes	Remedial actions
II. FILTERS		
1. Excessive pressure drop through filter	Dirty filter element	Replace filter element
	Filter is undersized	Consult manufacturer's flow charts; consider both body, size and port sizes when specifying
2. Contaminants carried through the filter	Elements omitted during servicing	Replace missing elements
	Elements not tightened enough	Tighten elements to prevent bypass
	Broken elements	Replace broken elements
	Element too coarse	Replace with finer graded elements
	Broken end cap from increased pressure drop caused by dirt build-up on entry side	Install standard particle filter ahead of the coalescing filter
3. Moisture in downstream air	Sump of filter bowl has collected too much water and water is re-entering the system	Drain bowl or install automatic drain
	Installation is wrong	Correct installation
	Location is incorrect : filter too close to the after cooler or too high in the plant ceiling	Relocate filter or install a dryer
	Body size is too large, causing low velocity and inefficient operation	Consult manufacturer's data
	Dew point of air is too high	Install a dryer
4. Plastic bowl crazed and breaking	Incompatible chemicals in contact with the plastic	Unless exact cause can be identified, substitute with metal bowls
	Excessive temperatures, pressures or sunlight	Unless damaging agent can be identified and eliminated, substitute metal bowls
III. REGULATORS		
1. Regulator cannot reach high set point	Pressure gauges are inaccurate	Ensure that gauge calibration is a regular maintenance function
	Insufficient upstream pressure	Measure and compare inlet pressure with outlet pressure
	Incorrect control spring range	Check model number for type used and replace
	Leakage in downstream circuit	Check fittings, valves, cylinders and regulators, correct as required
	Incorrect adjusting technique	To achieve reduced pressure, turn handle counter-clockwise below desire set point, then clockwise back up
2. Set point pressure becomes too high	External loads imposing a higher pressure	Use pressure relief valves, circuit changes or a venting regulator
	Leakage from inlet side : worn out poppet seal, seat or balancing seal	Check for leakage and replace parts as necessary
	Non-venting regulator can aggrevate pressure increase from other causes	Replace with venting regulator
3. Air often escaping from vent hole	External loads imposing a higher pressure	Use pressure relief valves, circuit changes or a ventilating regulator
	Leakage from inlet side : worn out poppet seal, seat, or balancing seal	Check for leakage and replace parts as necessary
4. Pressure too low when air is flowing	Incorrect adjusting technique	To achieve reduced pressure, turn handle counter-clockwise below the desired set point then clockwise back up
	Setting altered through vibration	Re-position adjustments and use locking features to secure position
	Leakage in downstream system	Check connections, component seals and correct as required
	Flow requirement is too high for regulator rating and/or plumbing	Install a larger regulator and/or larger plumbing
5. Chatter and vibration	Load instability from friction, turning over-center or reaching a natural frequency	Requires system analysis
	Regulator response to load changes is too fast or too slow	Change control springs, poppet return springs or the set-point.
	Regulator design has an inherent instability in this application	Change in springs or set-point may help or it may be necessary to switch regulators

Trouble/Fault	Probable causes	Remedial actions
6. Delay or lack of reverse flow	Regulator is not designed for reverse flow	Check manufacturer's specifications
	Inlet pressure exhausts too slowly	Check exhaust path for adequate capacity; check path for restricting flow control valves
	Downstream pressure is above the set-points, regulator is exhausting through vent path rather than reverse flow	Alter system conditions to keep downstream pressure at or below set-point before reverse flow starts
IV. LUBRICATORS		
1. Oil not delivered from the lubricator	Empty reservoir bowl	Institute program of regular refilling, or use an automatic refill system
	Clogged passageways	Disassemble and clean
	Closed needle valve	Check adjustment
	Torn restrictor	Replace the broken restrictor
	Internal parts incorrectly assembled	Disassembled and reassemble carefully
	Clogged pick-up tube inlet	Clean away debris
	Non-vertical positioning	Reposition and/or relocate the lubricator
2. Oil delivery is delayed	Initial start up delays are natural	Allow a few minutes of sustained air flow to fill internal passageway in the lubricator with oil
	Internal leakage in oil passageways	Disassemble and inspect for missing, damaged or improperly assembled parts
	Clogged pick-up tube inlet	Clean away debris
3. Too much oil delivery	Improper needle valve adjustment	Readjust as necessary
	Reverse flow through the lubricator	Use a quick exhaust valve at the cylinder port or locate the lubricator just upstream of the quick exhaust
4. Poor component performance even with oil delivery	Tortuous flow path from lubricator	Relocate the lubricator
	Incorrect oil type	Use recommendations of the component manufacturer
	Decrease in oil delivery rate	Periodic variation of flow rate

Trouble/Fault	Probable causes	Remedial actions
	Water condensation in the oil reservoir may occur in systems left unoperated for long periods	Manually drain from the bottom of the bowl reservoir
5. Reservoir bowl crazed	Incompatible oil with plastic material; excessive temperatures, pressures or sunlight	Use only mineral based oils or use metal bowls
V. AIR CYLINDERS		
1. Cylinder fails to move the load when valve is actuated	Binding in machine linkage	Check linkage to ensure that excessive friction loads are not present
	Pressure too low	Check the pressure at the cylinder to make certain that it is in accordance with circuit requirements
	Cylinder undersized for loads	Re-calculate force needs and install appropriate sized cylinders to carry the load
	Piston rod broken at piston end	Disassembled and replace piston rod
2. Erratic cylinder action	Valve sticking or binding	(*a*) Check for dirt or gummy deposits (*b*) Check for worn parts
	Cylinder sticking or binding	(*a*) Check for overtightened packing on rod seal or piston (*b*) Check for mis-alignment or worn parts
3. Cylinder body seal leak	Loose tie rods	Tighten the tie rods according to manufacturer's recommendations
	Excessive pressure	Reduce the pressure to the rated limits
	Pinched or extruded seal	Replace the cylinder body seal
	Seal deterioration	Check the compatibility of seal material with the lubricant used
4. Rod gland seal leak	Torn or worn seal	Examine the piston rod for dents and nicks. Replace the piston rod if the surface is rough

Trouble/Fault	Probable causes	Remedial actions
5. Excessive or rapid piston seal wear	Seal installed incorrectly	Check installation instructions and make necessary corrections
VI. AIR MOTORS		
1. Motor won't run	Air pressure too low	Check leaking air lines, small capacity hoses and compressor adequacy
	Insufficient lubrication	Proper lubrication by inline oilers or lubricators
	Rotor rubbing	Check the bearing wear
2. Lack of power	Internal air leakage and low air pressure	Check leaking air lines
	Worn vanes	Chipped, cracked, loose or rough edged vanes should be replaced
	Worn bearing plates	(*a*) If galling is only slight, sanding the plate to remove the burns (*b*) If wear is excessive replacement is necessary
3. Excessive vane wear	Dirty air	Strainers should be located at the inlet ports to prevent particles of dirt and rust from entering the motor
VII. VALVES		
1. Valve blows to exhaust	Inlet poppet not seating properly	(*a*) Poppet is damaged, it must be replaced (*b*) Dirt in poppet seats, clean it (*c*) Poppet seat damaged. Replace the entire valve body assembly
	Nicked, torn or swelling seals	Replace it
	Cylinder leaks	Leakage in the packing of the air cylinder connected to the valve. Replace the packings
	Damage spools	Replace it
	Air supply pressure too low and causes the valve to actuate partially	Inspect the system for undersized supply lines, sharp bends, fittings and clogged filter elements or a defective pressure regulator and adjust

Trouble/Fault	Probable causes	Remedial actions
	Water or oil contamination	Ensure that the air is dry and that the air filter is drained frequently
2. Poppet chatters	Low pilot or signal pressure	Check the valve specification for minimum pilot or signal pressure required
3. Spool valve action is sluggish	Swollen seals	Replace it
	Varnish deposits in spool valve	Remove varnish using a water soluble detergent or solvent such as kerosene
	Air supply pressure low	Inspect the system
	Low pilot or signal pressure	Check the valve specification for minimum pilot or signal pressure requirements
	Poor or no lubrication	Check the system lubricator to see that it is working as it should
	Faulty silencer/muffler	(*a*) Remove the silencer to see if valve performance has improved. (*b*) Clean the silencer to see if valve performance has improved. (*c*) Verify if the silencer is of adequate size
	Water or oil contamination	Ensure that the supply air is dry
4. Air flow is normal only in actuated position	Broken return spring	Replace the return spring
5. Solenoid buzzes	Low voltage at solenoid	Voltage should be checked at the solenoid coil and repaired
6. Solenoid burns out	High transient voltage	Isolate solenoid circuits from main power circuits
7. Sequence valve gives erratic timing	Faulty piston seal	Replace it
	Excessive lubrication	Check the system lubrication
	Fluctuating air pressure	Install a pressure regulator set at the systems lowest expected pressure
	Accumulated water	Re-route the pilot supply lines to eliminate low points
8. Flow control valve does not respond to adjustment	Excessive lubrication	Check the system lubrication
	Incorrect installation	Install properly
	Dirt in valve	Clean the valve

Trouble/Fault	Probable causes	Remedial actions
VIII. PIPELINES AND HOSES		
1. Pressure drop due to leakage of compressed air	Loose joints, fittings or glands	Tighten them
	Ruptured pipes and hoses	Replace the pipes and hoses
2. Pressure rises at specific points	Pipes, hoses are blocked	Clean and remove dirt
	Pipes, hoses are bent	Change them
3. Noise level is high	Silencer stops working	Clean it

REVIEW AND SUMMARY

✓ *The term **trouble-shooting** refers to an organised and systematic study of the problem and a logical approach to the difficulty faced in a system.*

✓ *A fault finding chart, also known as **tree-branching chart**, is used to simplify the complex fault finding process in a fluid circuit.*

✓ *In this chapter the various faults, probable causes, and remedies of both hydraulic and pneumatic systems have been presented in tabular form separately.*

KEY TERMS ONE SHOULD REMEMBER

Trouble-shooting
Faults
Causes
Fault diagnosis
Fault finding chart
Tree-branching chart
Troubleshooting of hydraulic system
Troubleshooting of pneumatic system

REVIEW QUESTIONS

Short Answer Type Questions

1. List four basic requirements on which the life of the fluid power systems depend.
2. List some common types of faults that can be found in hydraulic systems.
3. List some common causes of hydraulic system breakdown.
4. What does the term troubleshooting refer ?
5. What is the purpose of a tree-branching chart ?
6. List any six common types of pump faults.
7. If a pump is delivering insufficient or no oil, what are all the possible causes and also give remedies for them.
8. List any four causes for a pump making more noise.
9. List any two types of faults that can be found in each of the following hydraulic valves :
   (*a*) Relief valves, (*b*) Directional control valves,
   (*c*) Sequence valves, and (*d*) Flow control valves
10. If a hydraulic motor does not provide the proper speed and torque, what could be the probable causes for it.
11. What will you do to reduce/prevent excessive heating of oil in a hydraulic system ?
12. List any two types of faults that can be found in each of the components of a FRL unit.
13. If an air cylinder produces erratic cylinder action, identify the probable causes and also give remedies for them.
14. What are the probable causes and remedies for the problem of leakage of compressed air in pneumatic systems ?

Essay Answer Type Questions

1. (*a*) What do you mean by tree-branching chart ? Illustrate how it can help in fault finding and fault diagnosis for a hydraulic system.
   (*b*) Draw and explain a tree-branching chart for a pneumatic system.
2. Tabulate the various faults, probable causes, and also the remedial actions for the following hydraulic system components :
   (*i*) Pump, (*ii*) DC valve,
   (*iii*) Hydraulic motors, and (*iv*) Hydraulic cylinders.
3. Enlist the various faults, probable causes, and also the remedial actions for the following pneumatic system components :
   (*i*) Compressor, (*ii*) FRL unit,
   (*iii*) Air cylinder, and (*iv*) Pipelines and hoses.

□□

Two Mark
Questions & Answers

TWO MARK QUESTIONS & ANSWERS

CHAPTER 1 : INTRODUCTION TO FLUID POWER

1. ***Define the term fluid power.***

Fluid power may be defined as the technology that deals with the generation, control, and transmission of power using pressurized fluids.

2. ***Distinguish between fluid transport and fluid power systems.***

✓ The objective of the fluid transport systems is to transport/deliver fluids from one place to another place to achieve some useful purpose.

✓ The fluid power systems use pressurized fluids to produce some useful mechanical movements to accomplish the desired work.

3. ***Name three basic methods of transmitting power.***

1. Electrical power transmission,
2. Mechanical power transmission, and
3. Fluid power transmission,
   (*a*) Hydraulic power transmission, and
   (*b*) Pneumatic power transmission.

4. ***Under what situations, electrical, mechanical, and fluid power transmissions are suitable ?***

✓ Electrical power transmissions are suitable for power transmission over long distances.

✓ Mechanical power transmissions are suitable for the transmission of motion and force over relatively short distances.

✓ Fluid power transmissions are suitable for power transmission over intermediate distances.

5. ***What is the fundamental difference between hydraulics and pneumatics ?***

The hydraulic system employs pressurised liquid (such as oil) as the fluid medium whereas the pneumatic system employs compressed air.

6. ***List any four advantages of using the fluid power.***

1. Ease and accuracy of control.
2. Multiplication of force.
3. Constant force or torque.
4. Simplicity, safety, and economy.

7. ***Why are hydraulic systems preferred for heavy work than the pneumatic systems ?***

The hydraulic power systems can generate and transmit large torques and forces with high pressures to any part of a machine. That's why they are preferred for heavy work.

8. ***In comparison with hydraulic systems, why are pneumatic systems are suitable only for low load and low power applications ?***

Since pneumatic pressures are quite low due to the compressor design, the pneumatic systems are suitable only for low load and low power applications.

9. ***What is it not possible to obtain a precise actuator control in pneumatic systems ?***

Due to a high compressibility of air, it is impossible to obtain a precise actuator control in pneumatic systems.

10. ***List any four applications of fluid power in the manufacturing industry.***

1. Hydraulic presses,
2. Pneumatic hand tools,
3. Hydraulic and pneumatic fixtures, and
4. Pneumatic driven automatic indexing machine.

11. ***What are the two main types of fluid power systems ?***

1. Hydraulic power systems, and
2. Pneumatic power systems.

12. ***What are the basic components that are required for a hydraulic system ?***

The six basic components of a hydraulic system are :

1. Reservoir (or tank),
2. Pump,
3. Prime mover,
4. Valves,
5. Actuator, and
6. Fluid-transfer piping.

13. ***List the basic components of a pneumatic system.***

1. Reservoir (or air tank),
2. Compressor,
3. Prime mover,
4. Valves,
5. Actuator, and
6. Fluid-transfer piping.

14. ***What is the purpose of an actuator ?***

An actuator is used to convert the fluid energy into mechanical force or torque to do useful work.

CHAPTER 2 : FLUIDS AND THEIR PROPERTIES

1. ***What are the primary functions of a fluid in any fluid power system ?***

The primary functions of a fluid are as follows :

1. To transmit power.
2. To lubricate moving parts.
3. To seal gaps and clearances between mating components.
4. To dissipate heat generated by internal friction.
5. To prevent rust and corrosion.

2. ***Differentiate between a liquid and a gas.***

Sl.No.	Liquid	Gas
1.	Posses a definite volume for a given mass, but conforms to the shape of the container.	Has a definite mass, but does not possess a definite volume and conforms to the shape of the container.
2.	Incompressible fluid.	Compressible fluid.
3.	It forms a free surface.	It expands and occupies the whole volume of the container.

3. ***What is density of a fluid ? What are the three different ways of expressing it ?***

✓ The density of a fluid is that quantity of matter contained in unit volume of the substance.

✓ The three ways of expressing the density are : 1. Mass density, 2. Weight density, and 3. Specific gravity (or relative density).

4. ***What is meant by 'viscosity' of a fluid ? Also state Newton's law of viscosity.***

✓ Viscosity is the measure of the ability of a fluid to flow. It is the measure of the fluid's internal resistance to shear or flow at a definite temperature and pressure.

✓ ***Newton's law of viscosity :*** It states that the shear stress on a fluid element layer is directly proportional to the rate of shear strain.

5. ***What are the undesirable effects when an oil having very high viscosity is used ?***

When the oil is too thick (*i.e.*, oil having very high viscosity), the following undesirable effects will result in the system :

1. Increase in load and hence increased power loss.
2. High operating temperatures because there will be internal friction.
3. Excessive wear of parts.
4. Reduced internal leakage.

6. ***What are the undesirable effects when an oil viscosity is too low ?***

When an oil viscosity is too low, then the following undesirable effects will result in the system :

1. Less internal friction.
2. Smaller pressure losses in pipes and valves.
3. Increase in control action and component response.
4. Increased internal and external leakage.
5. Cannot lubricate properly.

7. ***State the effect of temperature and pressure on viscosity of liquids.***

The viscosity of the liquids decreases with increase in temperatures whereas the viscosity increases with increasing pressure.

8. ***State the effect of temperature and pressure on viscosity of gases.***

The viscosity of gases increase with increase in temperature. Over the normal range of pressures, the viscosity of gases is found to be independent of pressure.

9. ***"The viscosity of liquid decreases but that of gases increases with increase in temperature"—Why ?***

✓ Since the shear stress in the liquids (due to the intermolecular cohesion) decreases with increase of temperature, therefore the viscosity of liquid decreases with increase in temperature.

✓ If the temperature of a gas increases, the molecular interchange will increase. Therefore the viscosity of a gas increases with increase in temperature.

10. ***What is viscosity index ? What do you infer from V.I. number of an oil ?***

✓ The viscosity index (V.I) of a liquid is a number indicating the effect of a change in temperature on viscosity.

✓ The rate of change in viscosity with changes in temperature is relatively less with high V.I. oils than the low V.I. oils.

11. ***What is meant by the term compressibility of a fluid ? Give the relationship between compressibility and bulk modulus.***

✓ The compressibility is the fractional change in a unit volume of fluid per unit change of pressure. Mathematically,

$$\text{Compressibility, } C = \frac{(\Delta V/V)}{\Delta P}$$

✓ Bulk modulus is the reciprocal of compressibility. Mathematically,

$$\text{Bulk modulus, } K = \frac{1}{\text{Compressibility}} = \frac{\Delta P}{\left(\frac{\Delta V}{V}\right)}$$

12. ***Why should a hydraulic fluid have high bulk modulus ?***

The higher the bulk modulus, the less elastic or more stiffer the fluid. High bulk modulus values are desirable since they result in more stable and less elastic systems.

13. ***Define cloud point of an oil. Also give its significance.***

✓ ***Definition :*** Cloud point is defined as the temperature at which wax or other dissolved solids beings to crystallise and become noticeable when liquids are chilled under specified conditions.

✓ ***Significance :*** The cloud point is of interest for use at low temperatures.

14. ***Define pour point of an oil. Also mention its significance.***

✓ ***Definition :*** The pour point of an oil is the temperature below which the oil will not flow freely.

✓ ***Significance :*** This property is very important for hydraulic systems required to operate in extremely cold weather.

15. ***Define the terms 'flash' and 'fire' points, relative to hydraulic fluids.***

✓ ***The flash point*** is the minimum temperature at which sufficient liquid is vaporised under specified conditions to create a mixture that will burnt if ignited.

✓ ***The fire point*** is the minimum temperature at which sufficient vapour is continuously generated to sustain combustion.

16. ***Mention the significance of flash and fire points.***

Flash and fire points indicate the temperature at which the liquid begins to volatilize. A lower flash or fire point is an indication that the liquid has become contaminated with a more volatile product (such as fuel).

17. ***What is demulsibility ? Write its significance.***

✓ The property of a hydraulic fluid to separate rapidly and completely from moisture and to resist emulsification is known as demulsibility.

✓ ***Significance :*** This property is significant because the operation of many hydraulic systems are conducive to the forming of moisture or of stable water-in-oil emulsions.

18. ***What is oxidation stability ?***

Oxidation stability is defined as the ability of a liquid to resist reaction with oxygen or oxygen-containing compounds.

19. ***Define the following terms, with reference to hydraulic fluids :***

(a) Lubricity, (b) Compatibility, and (c) volatility

(*a*) ***Lubricity*** is the ability of a liquid to impart low friction under boundary conditions.

(*b*) ***Compatibility*** is the ability of the hydraulic fluid to be compatible with the system.

(*c*) ***Volatility*** of a liquid describes the degree and rate at which it will vapourize under given conditions of temperature and pressure.

20. ***What is neutralization number of hydraulic fluid ? Write its significance.***

✓ The neutralization number is a measure of acidity or alkalinity of a hydraulic fluid.

✓ High acidity causes the oxidation rate in an oil to increase rapidly.

21. ***List few required properties of a good hydraulic fluid.***

1. Stable viscosity characteristics.
2. Good lubricity.
3. Compatibility with system materials.
4. Stable physical and chemical properties.
5. Good heat dissipation capability.
6. High bulk modulus and degree of incompressibility.

22. *Name any four hydraulic fluids that are commonly used.*
    1. Petroleum oils.
    2. Water-in-oil and oil-in-water emulsions.
    3. Glycols.
    4. Phosphate esters.

23. *Name any three fire resistant fluids.*
    1. Water-in-oil emulsions.
    2. Water glycols.
    3. Phosphate esters.

24. *Why is water not commonly used as a hydraulic fluid ?*

    Because the water exhibits the following disadvantages :
    1. Water does not possess lubricating property.
    2. Water evaporates soon and hence it can be used only over a limited range of temperature.
    3. It is high corrosive in nature.

CHAPTER 3 : FLUID POWER SYMBOLS

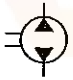
1. *What are fluid power symbols ?*

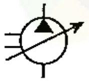
Fluid power symbols are used to represent individual components in fluid power circuit diagrams, which identify components and their functions uniquely.

2. *Draw the graphic symbols for the following pumps :*

   (a) Fixed displacement bidirectional pump, and

   (b) Variable displacement unidirectional pump.

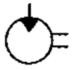
(a) 

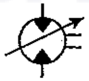
(b) 

3. *Draw the ANSI symbols for the following motors :*

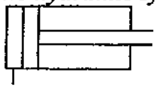
   (a) Fixed displacement unidirectional motor, and

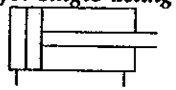
   (b) Variable displacement bidirectional motor.

(a) 

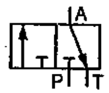
(b) 

4. *Give the hydraulic symbols for single-acting and double-acting cylinders.*

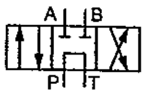
(a) 

(b) 

5. *Give the fluid power symbols for the 3/2- and 4/3-way valves.*

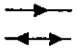
(a) 

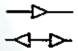
3/2 – way valve

(b) 

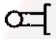
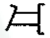
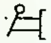
4/3 – way valve

6. *How can you indicate the direction of flow (i) for hydraulic fluid, and (ii) for pneumatic fluid.*

(*i*) Filled triangle  Indicates the direction of flow for hydraulic fluid (system).

(*ii*) Unfilled triangle  Indicates the direction of flow for pneumatic fluid (system).

7. *For the following graphic symbols shown, identify their mode of operation/actuation.*

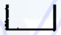
(*a*)  (*b*)  (*c*)  (*d*)

(*a*) Push button actuation, (*b*) Pedal actuation,

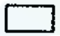
(*c*) Lever actuation, and (*d*) Solenoid actuation.

8. *Draw the ANSI symbols for the following hydraulic components :*

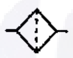
   (a) Reservoir, (b) Filter, (c) Cooler, and (d) Accumulator.

(a) 

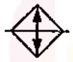
Vented reservoir



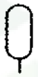
Pressurised reservoir

(b) 

Filter

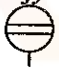
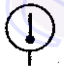
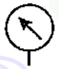
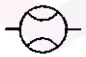
(c) 

Cooler

(d) 

Accumulator

9. *The following graphic symbols are used for indicating some measuring devices. Identify them.*

(*a*)  (*b*)  (*c*)  (*d*) 

(*a*) Filling level indicator, (*b*) Thermometer,

(*c*) Pressure gauge, (*d*) Flow meter.

CHAPTER 4 : BASICS OF HYDRAULICS

1. *Distinguish between gauge and absolute pressures. Give the relationship between them.*

   ✓ If the pressure is measured with reference to the atmospheric pressure, then it is called *gauge pressure*. The pressure measured with respect to vacuum is called an *absolute pressure*.

   ✓ ***Relationship :*** Absolute pressure = Gauge pressure + Atmospheric pressure

2. *State Pascal's law (or) State the basic law that is important in applying fluid power.*

Pascal's law states that the pressure generated at any point in a confined fluid acts equally in all directions.

3. *Name any two applications of Pascal's law.*

1. Bramah's hydraulic press.
2. Air-to-hydraulic pressure booster.

4. *What is the purpose of a hydraulic press ?*

The hydraulic press amplifies the hydraulic force in the hydraulic systems. That is, in a hydraulic press a small input force is applied to generate a large output force.

5. *What is the use of air-to-hydraulic pressure booster ?*

The air-to-hydraulic pressure booster is a device used for converting compressed air into the higher hydraulic pressure, which is required for operating hydraulic cylinders.

6. *Differentiate between laminar and turbulent flow.*

- ✓ A laminar flow is one in which paths taken by the individual particles do not cross one another and move along well-defined paths. The laminar flow is characterised by the fluid flowing in smooth layers of laminae.
- ✓ A turbulent flow is that flow in which fluid particles move in a zig-zag way. The turbulent flow is characterised by continuous small fluctuations in the magnitude and direction of the velocity of the fluid particles.

7. *What is Reynold's number ? Write its significance with reference to fluid power systems.*

✓ Reynolds number, $\text{Re} = \dfrac{\rho V D}{\mu} = \dfrac{VD}{\nu}$

where ρ = Density of the liquid,
V = Velocity of flow,
D = Diameter of the pipe,
μ = Absolute viscosity of the fluid, and
ν = Kinematic viscosity of the fluid.

✓ Reynold's number is the basis for determining the laminar and turbulent flow. If $\text{Re} < 2000$, then the flow is laminar; and if $\text{Re} > 4000$, then the flow is turbulent.

8. *Name two causes of turbulence in fluid flow.*

(*i*) More resistance to flow.
(*ii*) Greater energy loss.

9. *If the temperature increases so that the fluid viscosity decreases, would the Reynolds number increase, decrease, or remain the same ?*

Since $\text{Re} = \dfrac{\rho V D}{\mu} = \dfrac{VD}{\nu}$, any decrease in fluid viscosity would increase the Reynolds number.

10. *What is meant by flow rate ?*

Flow rate (or discharge) is the volume of the liquid flowing through a pipe in a specific period of time. Mathematically, $Q = \dfrac{V}{t} = A \times V$

11. *State the continuity equation.*

Continuity equation states as : "If no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be same". Mathematically,

$$A_1V_1 = A_2V_2 = A_3V_3$$

12. *State Bernoulli's equation.*

Bernoulli's equation states as follows : "In an ideal, incompressible fluid when the flow is steady and continuous, the sum of potential energy, kinetic energy and pressure energy is constant across all cross sections of the pipe." Mathematically,

$$z_1 + \frac{V_1^2}{2g} + \frac{P_1}{w} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{w}$$

13. *List out the various energy losses when liquid flows through a pipe.*

1. Major energy losses

   This loss is due to friction.

2. Minor energy losses

   These losses are due to :

   (*i*) Losses in valves and pipe fittings.
   (*ii*) Sudden enlargement/Contraction of pipe.
   (*iii*) Bend in pipe, *etc.*

14. *Give the Darcy's equation. What is the use of it ?*

✓ The Darcy's equation for the head losses in pipes is as follows :

$$H_L = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

✓ The Darcy's equation is used to calculate the energy losses due to friction in the pipe.

15. *Write down the Hagen-Poiseuille equation.*

The Hagen-Poiseuille, to find frictional losses in laminar flow, is as follows :

$$H_L = \frac{64}{\text{Re}}\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

16. *Define the term relative roughness.*

The relative roughness is defined as the pipe inside surface roughness (ε) divided by the inside diameter of the pipe (D).

$\therefore$ Relative roughness $= \dfrac{\varepsilon}{D}$

17. ***What is a Moody diagram ? Write its use.***

✓ The Moody diagram contains many curves. The curves indicate the value of friction factor as a function of Reynolds number and relative roughness.

✓ The Moody diagram can be used to determine the friction factor for use in Darcy's equation.

18. ***Give the expression to calculate the loss of head in the valves and fittings of a pipe.***

The loss of head in the various valves and fittings is given by :

$$H_L = K\left(\frac{V^2}{2g}\right)$$

19. ***Name any three flow-measuring devices.***

1. Rotometer,
2. Turbine flowmeter, and
3. Orifice flowmeter.

20. ***Name any two pressure-measuring devices.***

1. Bourdam gauge, and 2. Schrader gauge.

CHAPTER 5 : PUMPS – THE SOURCE OF HYDRAULIC POWER

1. ***What is the function of a hydraulic pump ?***

A hydraulic pump is a device which converts mechanical energy into hydraulic energy.

2. ***How can you classify pumps ?***

1. Positive displacement pumps.
   (*a*) Rotary pumps (such as gear pumps, and vane pumps)
   (*b*) Reciprocating pumps (such as piston pumps)
2. Non-positive displacement pumps.

3. ***What are positive displacement pumps ? Why are they called so ?***

✓ The positive displacement pumps discharge a fixed quantity of fluid into the hydraulic system per revolution of pump shaft rotation.

✓ Since the flow of fluid is guaranteed on every revolution of the shaft, this type of pump is named as 'positive' displacement pump.

4. ***Name any four positive displacement pumps.***

1. External and internal gear pumps.
2. Lobe and screw pumps.
3. Vane pumps.
4. Piston pumps.

5. ***Why are positive displacement pumps universally used in fluid power industries ?***

Positive displacement pumps are primarily used where pressure development is the prime requirement. This type of pumps is capable of delivering high pressure fluid, so it is universally used in fluid power systems.

6. ***What do you mean by non-positive displacement pumps ?***

In non-positive displacement pumps, the fluid flow is achieved by using inertia of the fluid in motion.

7. ***Where are non-positive displacement pumps employed ? Why ?***

The non-positive displacement pumps are suitable for low-pressure, high-volume flow applications. Since these pumps cannot withstand high pressures, they are used only for transporting fluid from one place to another.

8. ***Why are centrifugal (or non-positive displacement) pumps not preferred for fluid power applications ?***

Because the centrifugal pumps cannot withstand high pressures. Also they are suitable for low-pressure high-volume flow applications.

9. ***Name any four types of gear pumps used in hydraulic systems.***

1. External gear pumps, 2. Internal gear pumps,
3. Lobe pumps, and 4. Screw pumps.

10. ***Why all the gear pumps are fixed displacement pumps ? (or) Why gear pumps cannot be used as variable displacement pumps ?***

In gear pumps, the volumetric displacement depends on the design parameters (*i.e.*, diameter and width of gear teeth) of gears and they cannot be varied. So the displacement cannot be varied in gear pumps.

11. ***What type of gears are generally used in gear pumps ?***

The gears in the gear pumps can be of spur gear, helical gear or herringbone gear.

12. ***How can you specify a pump ?***

A pump can be specified by its capacity, discharge pressure, and speed of rotation.

13. ***Which pump—external gear, internal gear, screw, vane and piston—generates the least noise ? Why ?***

Screw pump generates the least noise, because of rolling action of the screw spindles. Also in the screw pump, the fluid does not rotate but moves linearly.

14. ***Name two designs of vane pumps.***

1. Unbalanced vane pumps, and
2. Balanced vane pumps.

15. *Distinguish between fixed displacement and variable displacement pumps ?*

In fixed displacement pumps, the displacement of the pump cannot be varied by any means. But in variable displacement pumps, the displacement of the pump can be varied by some suitable arrangements.

16. *When do you call a vane pump as a balanced or unbalance one ?*

A vane pump can be referred as unbalanced pump if all the pumping action takes place on one side of the rotor. But the balanced vane pump has two intake and two outlet ports which are diametrically opposite to each other.

17. *How can the unbalanced vane pump be used as a variable displacement pump ?*

In unbalance vane pump, the variable displacement can be provided by mechanically varying the eccentricity.

18. *What are the advantages of balanced vane pumps over the unbalanced vane pumps ?*

1. The balanced vane pumps eliminate the bearing side loads and thus permit higher operating pressures.
2. The balanced vane pumps have much improved service lives over simpler unbalanced vane pumps.

19. *What are piston pumps ? Name the two basic types of piston pumps.*

✓ In piston pumps, the pumping action is affected by a piston that moves in a reciprocating cycle through a cylinder.

✓ ***Types :*** 1. Axial piston pumps, and
2. Radial piston pumps.

20. *How can you vary the displacement in an axial piston pump ?*

The variable displacement in an axial piston pump can be achieved by altering the angle of the swash plate (or offset angle). Because in axial pumps, this swing angle determines the piston stroke and hence the pump displacement.

21. *Differentiate between axial and radial piston pumps.*

In axial piston pumps, the pistons move in-line or parallel to the shaft centre-line. But in radial piston pumps, the pistons move perpendicularly to the shaft centre-line.

22. *Define volumetric efficiency of a pump. Also write its significance.*

✓ Volumetric efficiency is the ratio between the actual flow rate produced by the pump and the theoretical flow rate that the pump should produce.

$$\therefore \quad \eta_{vol} = \frac{Q_A}{Q_T} \times 100$$

✓ ***Significance :*** The volumetric efficiency indicates the amount of leakage within the pump.

23. *Define mechanical efficiency of a pump. What does it indicate ?*

✓ Mechanical efficiency is the ratio between the theoretical power required to operate the pump and the actual power delivered to the pump.

✓ It indicates the amount of energy losses that occur due to reasons other than leakages.

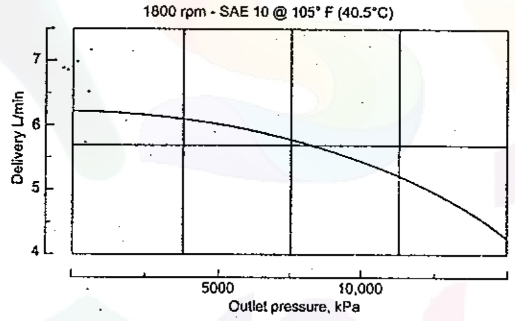
24. *What is overall efficiency of a pump ?*

✓ Overall efficiency is the ratio between the actual power delivered by pump and the actual power delivered to pump.

$$\therefore \quad \eta_0 = \eta_{vol} \times \eta_{mech}$$

✓ It indicates the amount of energy losses by all means.

25. *Draw the characteristic curve showing the relationship between discharge pressure and rate of delivery of an external gear pump.*



26. *What do you mean by 'slip' in pumps ?*

Slip is the leakage that occurs between the discharge and suction sides of a pump through the pump clearances.

27. *What is pump cavitation ? How can you avoid/eliminate it ?*

✓ The formation, growth, and collapse of vapour filled cavities or bubbles in a flowing liquid due to local fall in fluid pressure is called pump cavitation.

✓ Pump cavitation can be avoided by ensuring that the suction pressure is always greater than that required by the pump.

28. *What is pump ripple ?*

Small variations of fluid flow that takes place during pumping due to some design problems are called pump ripple.

29. *List some of the factors one should consider while selecting a pump for a specific application.*

(*i*) Safe and maximum system working pressure.
(*ii*) Rated pump performance.
(*iii*) Suitability of variable displacement control.
(*iv*) System flow rate requirement.

CHAPTER 6 : HYDRAULIC ACTUATORS : THE TRANSMITTER

1. ***What is the function of a hydraulic actuator ?***

A hydraulic actuator is used for converting hydraulic energy into mechanical energy.

2. ***How can you classify the hydraulic actuators ?***

1. Linear actuators (also called 'hydraulic cylinders'), and
2. Rotary actuators (also called 'hydraulic motors').

3. ***What is the function of a hydraulic cylinder ?***

The hydraulic cylinder is used to convert fluid power into linear mechanical force and motion.

4. ***Mention few applications of hydraulic cylinders.***

The hydraulic cylinders are basically used for performing work such as pushing, pulling, tilting, and pressing in a variety of engineering applications such as in material handling equipment, machine tools, construction equipment, and automobiles.

5. ***Name different types of hydraulic cylinders.***

1. Single acting cylinders,
2. Double acting cylinders,
3. Telescoping cylinders,
4. Tandem cylinders, and
5. Through rod cylinders.

6. ***By what means, single-acting cylinders are retracted ?***

The single-acting cylinders are retracted using gravity or by the inclusion of compression spring at the rod end of the cylinders.

7. ***Differentiate between a single-acting and a double-acting hydraulic cylinder.***

Single-acting hydraulic cylinders can deliver a force in only one direction. But in double-acting cylinders, liquid pressure can be applied to either side of the piston, thereby providing a hydraulic force in both directions.

8. ***What is the purpose of seals in hydraulic system ?***

The seals are used to prevent the internal and external leakages of hydraulic system.

9. ***What are the three types of seals used in a double-acting cylinder ? Also write their functions.***

1. ***Piston seals :*** They are provided in between piston and barrel to avoid any leakage.
2. ***Wipe or Scraper seal :*** It is fitted on the outside of the piston rod bearing to prevent grit, water or other matter being drawn into the bearing.
3. ***O rings :*** O rings, also called internal sealing rings, are fitted behind the bearing to prevent high pressure fluid leaking out along the rod.

10. ***Why are double-acting cylinders known as differential cylinders ?***

Since the piston rod is attached at one side only, the cylinder exerts greater force when extending [$F = P \times A_{piston}$] than when retraction [$F = P \times (A_{piston} - A_{rod})$]. This results in different pressure levels on either side of the piston and that's why double-acting cylinders are also called as differential cylinders.

11. ***What is meant by cylinder cushioning ?***

When the pressurised fluid is allowed to enter inside the cylinder, the piston accelerates and travels in the cylinder barrel. If the piston is allowed to travel at the same speed till the end of the stroke, it will hit the end cap with a great impact. To avoid this impact, the piston needs to decelerate at the end of the travel. The arrangement made at the end caps to achieve the same is called 'cylinder cushion'.

12. ***What is a telescopic cylinder ? When is it normally used ?***

✓ A telescopic cylinder consists of a series of rams (pistons) nested in a telescopic assembly which provide a long extension.

✓ Telescopic cylinders are useful for application requiring a long stroke but with only limited space available for the unextended ram.

13. ***What are tandem cylinders ? When are they normally used ?***

✓ A tandem cylinder is one in which two or more piston rod combinations are assembled as a rigid unit with all pistons mounted on single rod.

✓ The cylinders are used to obtain a low-force, high-speed action followed by a high-force, low-speed action.

14. ***What do you mean by double-rod cylinder ?***

A double-rod cylinder, also known as through-rod cylinder has piston rods extending from both ends of the cylinder. These cylinders produce equal force and speed on both sides of the cylinder.

15. ***Name few cylinder mountings.***

1. Side foot mount,
2. Centerline mount,
3. End foot mount,
4. Side-flush mount,
5. Rear flange mount,
6. Front flange mount,
7. Clevis mount,
8. Basic mount, *etc.*

16. ***What is the function of a hydraulic motor (or rotary actuator) ?***

The function of a hydraulic motor (or rotary actuator) is to convert hydraulic energy into rotary mechanical energy.

17. ***Name the basic types of rotary actuators. Which will provide the maximum degree of rotation ?***

✓ *Types :* 1. Continuous rotary actuator, and
(*a*) Gear motor, (*b*) Vane motors, and (*c*) Piston motors.
2. Limited rotation hydraulic motors.
(*a*) Vane type, and (*b*) Piston type.

✓ Continuous rotary actuators will provide the maximum degree of rotation.

18. ***How do you rate/specify a hydraulic motor ?***

The hydraulic motors are usually specified in terms of the torque developing capacity or differential pressure.

19. *Which hydraulic motor is generally the most efficient ? Why ?*

The piston motors are the most efficient motors. Because they are positive displacement motors.

20. *Mention few applications where piston motors are employed.*

Piston motors are suitable for low-speed, high torque traction applications such as earth-moving machinery, agricultural tractors, railway locomotive and other industrial applications.

21. *What do you mean by a limited rotation hydraulic motor ?*

The limited-rotation motors provide rotary output motion over a finite angle. Usually rotation of the shaft of these motors is 90°, 180°, or 270°.

22. *Mention few applications of limited rotation hydraulic motors.*

The important applications of limited rotation hydraulic motors include conveyor sorting, valve turning, air bending operations, flip over between workstations, positioning for welding, lifting, rotating, and dumping.

23. *With respect to hydraulic motors, define the terms volumetric and mechanical efficiency.*

✓ $$(\eta_{vol})_{motor} = \frac{\text{Theoretical flow rate motor should consume}}{\text{Actual flow rate consumed by motor}} \times 100$$

✓ $$(\eta_{mech})_{motor} = \frac{\text{Actual torque delivered by motor}}{\text{Torque motor should theoretically deliver}} \times 100$$

24. *What is meant by a fluid transmission device ?*

A fluid transmission device converts mechanical power into fluid power, transports this power, and then converts it back into mechanical power.

CHAPTER 7 : HYDRAULIC VALVES : THE REGULATOR

1. *What are the three important parameters that should be controlled in a hydraulic system ?*

1. Pressure,
2. Flow direction, and
3. Flow rate.

2. *What are control (or hydraulic) valves ?*

Control valves are devices used to control pressure, flow direction, or flow rate in hydraulic circuits.

3. *Name the three basic types of control valves based on their function.*

1. Directional control valves,
2. Pressure control valves, and
3. Flow control (or volume control) valves.

4. *What are the three types of control valves based on their configuration ?*

1. Poppet (or seat) valves,
2. Sliding spool valves, and
3. Rotary spool valves.

5. *What are the advantages of sliding-spool type valves over the poppet type valves ?*

1. Different operations can be achieved with a common body and different spools.
2. Reduced manufacturing cost.
3. Reduced fluid leakage rate.
4. All types of actuation are easily adaptable.

6. *What is the function of a DCV ?*

The function of a directional control valve (DCV) is to control the direction of flow in a hydraulic circuit.

7. *What are the function of check valves ?*

Check valves are used :

(*i*) to allow free flow in only one direction, and

(*ii*) to prevent any flow in the other direction.

8. *What is the difference between a simple check valve and a pilot check valve ?*

The simple check valve does not permit any reverse flow. The pilot-check valve can allow fluid flow in both directions, but the reversed flow depends upon the pilot actuation.

9. *What does a 4/3 control valve represent ?*

A 4/3 control valve has 4 ways and 3 positions.

10. *What are the different valve actuation methods used ?*

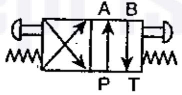
1. Manual actuation,
2. Mechanical actuation,
3. Electrical actuation, and
4. Fluid actuation.

11. *Draw the graphic symbol for the following DC valves :*

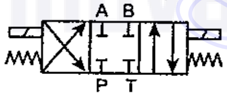
(a) Push button operated, four way, two position, spring offset DC valve, and

(b) Solenoid actuator, spring return 4/3 DC valve.

(*a*)



(*b*)



12. *What is a solenoid and how does it actuate the spool of a DC valve ?*

A solenoid is an electromagnetic coil. When it is energized, it creates a magnetic force that pulls the armature. The armature is connected to the spool of the valve and the valve is actuated.

13. *Mention the application of a (i) 3 way DC valve, and (ii) 4 way DC valve.*

(*i*) Three way DC valves are used to control single-acting linear actuators.

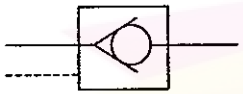
(*ii*) Four way DC valves are used to control double-acting actuators.

14. *What is the purpose of a shuttle valve ?*

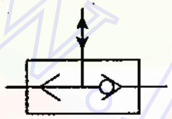
Shuttle valves are used when control is required from more than one power source. They are generally used to shift the fluid flow from the second and back up source, when the main source becomes inoperative.

15. *Draw the ANSI symbols for (i) a pilot-operated check valve, and (ii) a shuttle valve.*

(*a*)



(*b*)



16. *What are pressure control valves ? Mention their functions.*

✓ Pressure control valves are the devices used to control the fluid pressure in a system.

✓ Functions of pressure control valves are :

(*i*) To limit the maximum pressure in various circuit components as a safety measure.

(*ii*) To maintain the desired pressure levels in various parts of the circuits.

(*iii*) To unload system pressure.

(*iv*) To assist sequential operation of actuators in a circuit with pressure control.

17. *Name various types of pressure control valves.*

1. Pressure limiting (or relief) valves,
2. Pressure reducing valves,
3. Sequence valves,
4. Counter balance valves, and
5. Unloading valves.

18. *What is the use of a pressure relief valve in a hydraulic system ?*

The pressure relief valve protects a system from excessive fluid pressure over and above the design pressure limit.

19. *What is the purpose of a pressure reducing valve ?*

A pressure reducing valve is used to supply a prescribed reduced outlet pressure in a circuit and to maintain it at a constant value.

20. *What are sequence valves ?*

The sequence valves are used to control the fluid flow to ensure several operations in a particular order of priority in the system.

21. *What is the purpose of a counterbalance valve ?*

The counterbalance valve is used to permit free flow in one direction and restricted flow in the opposite direction.

22. *What is the function of an unloading valve ?*

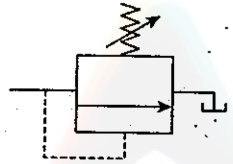
The unloading valve allows pressure to build up to an adjustable setting, then bypasses the flow as long as a remote source maintains the preset pressure on the pilot port.

23. *What is the use of a hydraulic fuse ?*

The hydraulic fuse, analogous to an electrical fuse, is used to prevent the system pressure from exceeding beyond the allowable limit in order to protect the system components from damage.

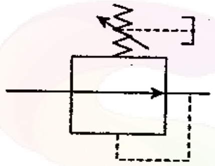
24. *Draw the graphic symbols for (i) a pressure relief valve, and (ii) a pressure reducing valve.*

(*i*)



Pressure relief valve

(*ii*)



Pressure reducing valve

25. *What are flow control valves ? Why are they referred as speed-control valves ?*

✓ Flow control valves, also known as volume-control valves, are used to regulate the rate of fluid flow to different parts of a hydraulic system.

✓ Since control of flow rate is a means by which the speed of hydraulic machine elements is governed, therefore flow control valves are also referred as speed-control valves.

26. *Name few non-pressure compensated flow control valves.*

1. Disk-type globe valve,
2. Plug-type globe valve,
3. Ball-type globe valve, and
4. Needle valve.

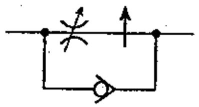
27. *What do you mean by a pressure-compensated flow control valve ?*

The flow rate through any orifice depends upon the pressure difference between its inlet and outlet. Therefore a constant pressure drop across the valve orifice is required to assure accurate flow control. This is accomplished with the pressure-compensated flow control valve.

28. *Why are flow control valves often temperature compensated ?*

Flow control valves can be affected badly by temperature changes which also change the viscosity of the fluid. Therefore often flow control valves have temperature compensation.

29. *Draw the graphic symbol for a pressure-compensated flow control valve.*



Symbol for pressure compensated flow control valve

30. ***With reference to a flow control valve, define the term capacity coefficient.***

The term capacity coefficient may be defined as the flow rate of water in Lpm that will flow through the valve at a pressure drop of 1 kPa.

CHAPTER 8 : ACCUMULATORS AND INTENSIFIERS

1. ***Name any six ancillary equipment commonly used in the hydraulic system.***

1. Fluid reservoir,
2. Filters and strainers,
3. Heat exchangers,
4. Pressure and temperature switches,
5. Accumulators, and
6. Intensifiers.

2. ***What is the purpose of a fluid reservoir ?***

- ✓ Fluid reservoirs are basically used to provide a storage facility for the hydraulic fluid used by the system.
- ✓ In addition, the reservoirs also serve to separate entrained air, remove contaminants, and dissipate heat from the fluid.

3. ***What is the purpose of a heat exchanger in hydraulic systems ?***

Heat exchangers, also known as hydraulic coolers, are devices used to dissipate the heat generated in a hydraulic system.

4. ***Why is pressure measurement considered as a crucial process in the troubleshooting of hydraulic circuits ?***

Because pressure measurement can provide a good indication of leakage problems and faulty components such as pumps, motors, valves, and actuators.

5. ***What is the use of a pressure switch ?***

A pressure switch is an instrument that automatically senses a change in pressure and opens or closes an electrical switching element when a predetermined pressure point is reached.

6. ***What is the use of a temperature switch ?***

A temperature switch is an instrument that automatically senses a change in temperature and opens or closes an electrical switching element when a predetermined temperature point is reached.

7. ***What is the use of a shock absorber in hydraulic systems ?***

A shock absorber is a device that brings a moving load to a gentle rest through the use of metered hydraulic fluid.

8. ***What is the function of an accumulator ? What electrical device is it analogous to ?***

- ✓ An accumulator is a pressure storage reservoir in which a non-compressible hydraulic fluid is retained under pressure from an external source.
- ✓ The function of hydraulic accumulator is analogous to that of a capacitor in an electrical circuit.

9. ***What are the three basic types of accumulators used in hydraulic systems ?***

1. Weight-loaded (or dead-weight) accumulators,
2. Spring-loaded accumulators, and
3. Gas-loaded accumulators.

10. ***What are the uses/functions of accumulators ?***

Accumulators are used as :

(*i*) Leakage compensator,
(*ii*) Auxiliary power source,
(*iii*) Emergency power source,
(*iv*) Hydraulic shock absorber,
(*v*) Fluid make-up device,
(*vi*) Holding device, *etc.*

11. ***Which type of accumulator operates at constant pressure ?***

The weight-loaded type accumulator operates at constant pressure.

12. ***What type of gas is used in gas-loaded accumulators ? Why is oxygen not used for this purpose ?***

- ✓ The inert gas such as nitrogen gas is used in gas-loaded accumulator.
- ✓ The air or oxygen are not used due to the danger of explosion.

13. ***What is meant by the term 'capacity' of an accumulator ?***

The maximum amount of energy that the accumulator can store is known as the capacity of the accumulator.

14. ***What are three significant accumulator operating conditions ?***

1. Recharging condition.
2. Charging (the fluid to maximum pressure) condition, and
3. Discharging (the fluid to minimum pressure) condition.

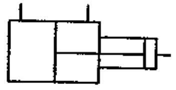
15. ***What is the function of a pressure intensifier ? What electrical device is it analogous to ?***

- ✓ Pressure intensifier, also known as pressure booster, is used to compress the liquid in a hydraulic system to a value above the pump discharge pressure.
- ✓ It is analogous to a step-up electrical transformer.

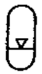
16. ***Define the term intensifier ratio.***

$$\text{Intensifier ratio} = \frac{\text{High outlet pressure } (P_i)}{\text{Low inlet pressure } (P_o)} = \frac{\text{Area of large piston } (A_o)}{\text{Area of small piston } (A_i)}$$

17. ***Draw the fluid power symbols for (i) a pressure intensifier and (ii) gas-loaded type accumulator.***



(i) Symbol for pressure intensifier



(ii) Symbol for gas-loaded accumulator

CHAPTER 9 : ELECTRICAL CONTROLS FOR FLUID POWER SYSTEMS

1. ***Why are electrical controls of fluid power systems preferred than the manual controls ?***

Because electrical controls offer the following features :

(*i*) They can be easily controlled.

(*ii*) They improve the overall control flexibility of fluid power systems.

(*iii*) They provide quick and accurate control operations.

(*iv*) They require less maintenance.

2. ***Name any four basic electrical devices commonly used in the control of fluid power systems.***

1. Push-button switches,
2. Limit switches,
3. Solenoids, and
4. Relays.

3. ***What is the use of a push-button switch ?***

The push-button switch is primarily used for starting and stopping of the machinery.

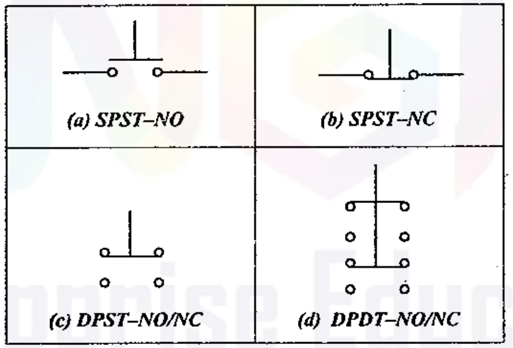
4. ***What are the four types of push-button switches ? Also draw their graphic symbols.***

(*i*) Single-pole single-throw—Normally open type (SPST–NO),

(*ii*) Single-pole single-throw—Normally close type (SPST–NC),

(*iii*) Double-pole single-throw type (DPST), and

(*iv*) Double-pole double-throw type (DPDT).



(a) SPST–NO *(b) SPST–NC* *(c) DPST–NO/NC* *(d) DPDT–NO/NC*

Graphic symbols for push-button switches

5. ***What are limit switches ? How do they differ from push-button switches ?***

✓ The limit switches are used to identify the extreme limits of the cylinder actuation.

✓ ***Difference :*** The difference between the push-button and limit switches is that push-button switches are actuated manually whereas the limit switches are mechanically actuated devices.

6. ***What is the purpose of a pressure switch ?***

The pressure switches are used to sense a change in pressure automatically, and opens or closes an electrical switch when a predetermined pressure is reached.

7. ***What is the use of a temperature switch ?***

The temperature switches are used to sense a change in temperature automatically, and opens or closes an electrical switch when a predetermined temperature is reached.

8. ***What is a solenoid ? Also state its use.***

✓ A solenoid is an electromagnetic mechanical transducer that converts an electrical signal into a mechanical output force.

✓ Solenoids provide a push or pull force to remotely operate fluid power valves.

9. ***What is the purpose of having an indicator lamp in an electric circuit of a fluid power system ?***

Indicator lamps are used :

(*i*) to identify which solenoid operator of a DC valve is energized, and

(*ii*) to indicate whether a hydraulic cylinder is extending or retracting.

10. ***What do you mean by an electrical relay ?***

The electrical relays offer simple ON/OFF switching action in response to a signal issued by a control system. Relays are commonly used to open or close the contacts and thereby energize or de-energize solenoids which operate at a high current level.

11. ***What is the purpose of a timer ?***

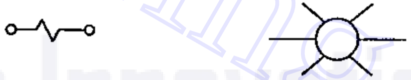
Timers, also known as ***time-delay relays,*** are time delay switches used to control the time duration of a working cycle.

12. ***Explain one situation where you use an electrical timer.***

The times can be adjusted to change the dwell period for many machinery operations. For example, in a drilling machine operation the timers provide a dwell, which allows the drill to pause for a predetermined time at the end of the stroke to remove the chips.

13. ***Draw the graphic symbols for the following :***

(a) Solenoid, and (b) Indicator lamp.



(a) Solenoid *(b) Indicator lamp*

14. ***What is a ladder diagram ?***

A ladder diagram is nothing but an electrical diagram showing the hardware connections between the various electrical control devices.

15. ***What are the uses of a ladder diagram ?***

Ladder diagrams provide a circuit designer with a practical means to examine input process and output functions to quickly plan the circuit layout design for a particular hydraulic or pneumatic application.

CHAPTER 10 : BASICS OF PNEUMATICS

1. ***Define 'pneumatics'.***

The pneumatics may be defined as that branch of engineering-science which deals with the study of the behaviour and application of compressed air.

2. ***Why is air used as the fluid medium in all pneumatic systems ?***

The air is popularly used as the fluid-medium in pneumatic systems due to the following reasons :

(*i*) Air is abundantly available.
(*ii*) It is safe to use (as it has the fire-proof characteristics).
(*iii*) It is very cheaper in cost.
(*iv*) Easier maintenance and easily handling.
(*v*) It can be exhausted easily to the atmosphere after use.

3. ***'Pneumatic systems cannot provide precise actuator control'—Why ?***

Due to the high compressibility of air pneumatic systems cannot provide precise actuator control.

4. ***'Pneumatic systems cannot be applied to high-pressure application'—Why ?***

Due to compressor design limitations, pneumatic systems can be applied only to low-pressure (less than 17 bars) applications.

5. ***For what type of application, you would prefer to use pneumatic systems rather than hydraulic systems.***

If the application requires speed, a medium amount of pressure, and only a fairly accurate feed, then pneumatic system can be used.

6. ***Give the composition of air.***

The main constituents of air by volume are 78% nitrogen, 21% oxygen. and 1% other gases such as argon and carbon dioxide.

7. ***What do you mean by standard air ?***

Standard air is sea-level air having a temperature of 20°C, pressure of 1.013 bar, and a relative humidity of 36%.

8. ***State the following perfect gas laws :***
(i) Boyle's law, (ii) Charles' law, and (iii) Gay-Lussac's law.

(*i*) ***Boyle's law*** states that if temperature remains constant, the pressure of a confined mass of gas will vary inversely with its volume.

(*ii*) ***Charles' law*** states that pressure remaining constant, the volume of a given mass of gas will vary directly as its absolute temperature.

(*iii*) ***Gay-Lussac's law*** states that volume remaining constant, the pressure of a confined mass of gas will vary directly as its absolute temperature.

CHAPTER 11 : AIR COMPRESSORS AND FLUID CONDITIONERS

1. ***What is the use of a compressor in a pneumatic system ?***

In pneumatic systems, compressors are used to compress and supply the required quantities of air.

2. ***What does staging mean ?***

Staging means dividing the total pressure among two or more cylinders by allowing the outlet from one cylinder into the inlet of the next cylinder and so on.

3. ***Why are multi-stage compressors preferred over single-stage compressors ?***

When the multistage compressors are used, the effective cooling can be implemented between stages. This effective cooling (*i*) reduces input power requirements, and (*ii*) increases the efficiency of the compressor.

4. ***What is the purpose of compressor starting unloader control ?***

The 'starting unloader control' is used to start the compressor whenever desired. This arrangement releases the pressure in the piping to the atmosphere so that the compressor can be started whenever needed.

5. ***How can you specify an air compressor ?***

Air compressors are generally specified by the following :

(*i*) Outlet pressure of air that can be delivered by the compressor,
(*ii*) Capacity of volume of air that can be delivered by the compressor, and
(*iii*) Compressor configuration and cylinder geometry.

6. ***What is the purpose of fluid conditioners ?***

The purpose of fluid conditioners is to make the compressed air more acceptable and suitable fluid medium for the pneumatic system components as well as for operating personnel.

7. ***Name any four fluid conditioners used in pneumatic systems.***

1. Filters, 2. Regulators,
3. Lubricators, and 4. Mufflers.

8. ***What is the function of air filters ?***

The function of air filters is to remove all foreign matter and allow dry, clean air to flow without restriction to the regulator and then on to the lubricator.

9. ***What is the purpose of an air pressure regulator ?***

The function of the air pressure regulator is to regulate the pressure of the incoming compressed air so as to achieve the desired air pressure at a steady condition.

10. ***What is the use of lubricators applied in pneumatic systems ?***

The function of an air lubricator is to add a controlled amount of oil with air to ensure proper lubrication of internal moving parts of pneumatic components.

11. ***What do you mean by FRL unit ?***

The combination of filter, regulator, and lubricator is often labelled as FRL unit or service unit.

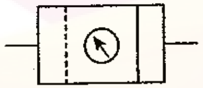
12. ***Why are mufflers used in pneumatic systems ?***

The function of mufflers is to control the noise caused by a rapidly exhausting air-stream flowing into the atmosphere.

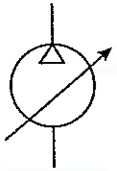
13. ***What is the need for air dryers ?***

The air dryers are needed to remove all water vapour/moisture from the air leaving the compressor.

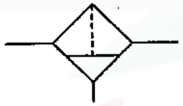
14. ***Draw the graphic symbol of a FRL unit.***



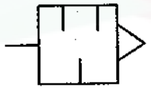
15. ***Draw the graphic symbol of (a) air compressor, (b) filter, and (c) Muffler.***



(a) Single, variable displacement compressor



(b) Filter-strainer



(c) Muffler

CHAPTER 12 : PNEUMATIC VALVES AND ACTUATORS

1. ***What are the functions of air control valves ?***

The main functions of pneumatic valves are :

(*i*) To start and stop pneumatic energy;

(*ii*) To control the directional flow of compressed air;

(*iii*) To control the flow rate of the compressed air; and

(*iv*) To control the pressure rating of the compressed air.

2. ***Mention the applications of a 2 way, 3 way, and 4 way D.C valves.***

Generally two way DC valves are used as on-off type valves; three way DC valves are used to control single-acting linear actuators; and four way DC valves are used to control double-acting actuators.

3. ***What is the purpose of a quick exhaust valve ?***

The quick (or fast) exhaust valve is used to exhaust the cylinder air to the atmosphere quickly, so as to increase the piston speed of cylinders.

4. ***What is the function of an air pressure regulator ?***

The air pressure regulator is used to supply a prescribed reduced outlet pressure in a pneumatic circuit and to maintain it at a constant value.

5. ***What is the function of a flow control valve in a pneumatic circuit ?***

Flow control valves are used to regulate the volumetric flow of the compressed air to different parts of a pneumatic system.

6. ***What is the function of a pneumatic actuator ?***

Pneumatic actuators are the devices used for converting the pressure energy of air into mechanical energy to perform useful work.

7. ***How do pneumatic actuators differ from hydraulic actuators ?***

Generally pneumatic actuators are of lighter construction and of lesser weight when compared to that of hydraulic actuators. This is because the pneumatic actuators are used mostly for low or medium pressure applications only.

8. ***What is the function of a pneumatic cylinder ?***

Pneumatic cylinders are the devices used for converting the air pressure into linear mechanical force and motion.

9. ***What is the function of an air motor ?***

The function of an air motor is to convert the pressure energy of the compressed air into rotary mechanical energy.

CHAPTER 13 : FLUID POWER CIRCUIT DESIGN

1. ***What are the four important factors that should be considered while designing a fluid power circuit ?***

1. Safety of operation,
2. Performance of desired function,
3. Efficiency of operation, and
4. Cost.

2. ***What is meant by hydraulic power pack ?***

✓ Hydraulic power pack consists of a pump, drive motor, mechanical couplings, oil reservoir, filters, coolers and valves assembled as a single unit to supply pressurized fluid.

✓ It provides pressure, direction, and flow control functions within the basic package.

3. ***What is the use of a regenerative circuit ?***

A regenerative circuit is used to speed up the extending speed of the double-acting cylinder.

4. ***Why is the load-carrying capacity of a regenerative cylinder small when the piston rod area is small ?***

We know that,

$$\left.\begin{array}{r}\text{Regenerative cylinder extending}\\ \text{load-carrying capacity}\end{array}\right\}, F_{load} = P \cdot Ar$$

Therefore when piston area (Ar) is small, then the load-carrying capacity of the regenerative cylinder will also be small.

5. ***Why is extension stroke faster than retraction stroke in a regenerative circuit ?***

This is because oil flow from the rod end regenerates with the pump flow to provide a total flow rater, which is greater than the pump flow rate to the blank end of the cylinder.

6. ***What do you mean by sequencing of cylinders ? Name some applications where it would be desirable to have sequencing of two cylinders.***

✓ In many applications, the operation of two hydraulic cylinders is required to be performed in sequence one after the another. This is known as sequencing of cylinders.

Applications : (*i*) In a drilling machine, clamping and drilling operations should be performed in a sequence.

(*ii*) In a punching machine, clamping and punching operations should be performed in a sequence.

7. ***What do you mean by synchornization of cylinders ? Name some applications where it would be desirable to have two cylinders synchronized in movement.***

✓ Synchronization of cylinders is the process of making cylinders to perform identical task at same rate.

✓ ***Application :*** The application of synchronizing of two cylinders can be found in material handling equipment to push heavy components. Also they are widely used in packing industries.

8. ***Name the various methods by which synchronization of cylinders can be achieved.***

1. By using double-end cylinders connected in series,
2. By using mechanically linked pistons,
3. By using hydraulic motors as metering devices.
4. By using flow control valves, and
5. By using air-hydraulic cylinders in series.

9. ***Name the three ways of applying flow control valves in a fluid power circuit.***

1. Meter-in circuit,
2. Meter-out circuit, and
3. Bleed-off circuit.

10. ***Differentiate between meter-in and meter-out circuits with respect to speed control circuits.***

✓ In meter-in circuit, the flow control valve is located in the line leading to the inlet port of the cylinder.

✓ In meter-out circuit, the flow control valve is located in the outlet line of the hydraulic cylinder.

11. ***When do you use (a) a meter-in, and (b) a meter-out circuit in the fluid power application ?***

✓ ***Meter-in circuits*** are generally used when the external load opposes the direction of motion of the cylinder. For example, the case of a hydraulic table, feed on a surface grinder.

✓ ***Meter-out circuits*** are commonly used when the external load acts in the same direction of motion of the cylinder. For example, the case of a load acting downward on the piston rod of a vertical cylinder.

12. ***What do you meant by bleed-off circuit control ?***

In the bleed-off circuit, the flow control valve is connected with its outlet port which is connected to the reservoir. The flow control valve controls flow to the cylinder by diverting an adjustable amount of pump's flow to the reservoir. Since oil delivered to the cylinder does not have to flow through the flow control valve, this circuit avoids the need of dumping excess oil through the relief valve.

13. ***What is the purpose of a fail-safe circuit ?***

Fail safe circuit is designed to safeguard the operator, the machine, and the workpiece. It prevents any possible injury to the operator or damage to the machine and the workpiece.

14. ***In what ways, pneumatic circuits differ from the hydraulic circuits ?***

1. Unlike in hydraulic circuits, the return lines are not required in pneumatic circuits.
2. Since most pneumatic circuits use a centralized compressor as their source of energy, generally no input device is shown in these circuits.

15. ***What are hydropneumatic circuits ?***

In some applications, the hydraulic and pneumatic circuits are coupled to get best use of the advantages of both oil and air mediums. These combination circuits are known as ***hydropneumatic*** or ***pneumohydraulic circuits.***

16. ***List any four advantages of employing hydropneumatic circuits.***

1. Using the combination circuit, the quick action of air and smooth, high pressure action of oil can be blended.
2. The hydropneumatic circuits will reduce space requirements.
3. These circuits increase the performance of the equipment.
4. These circuits will reduce initial and maintenance cost of original equipment.

17. ***What is meant by an air-over-oil system ?***

The air-over-oil system was both air and oil to obtain the advantages of each medium. By the use of these two media, the quick action of air and the smooth high-pressure action of oil can be blended.

CHAPTER 14 : SERVO SYSTEMS AND PROPORTIONAL CONTROLS

1. ***What is a servo system ?***

A servo system is one in which a comparatively large amount of power is controlled by small impulses or command signals and any errors are corrected by feedback signals.

2. ***List six elements of a basic closed-loop servo system.***

1. Command signal,
2. Servo amplifier,
3. Servo valve,
4. Actuator,
5. Load, and
6. Feedback transducer.

3. ***Mention the functions of the following :***

(a) Servo amplifier, and (b) Feedback transducer.

✓ ***The servo amplifier*** receives a low-power input signal and amplifies it to a higher power level.

✓ ***The feedback transducer*** measures the result at the load and sends a feedback signal to the amplifier unit.

4. ***What are servo valves ? Write their purpose in fluid power systems ?***

✓ Servo valves are nothing but DC valves having infinitely variable positioning capability.

✓ The servo valves are used to control not only the direction of fluid flow, but also the amount of flow.

5. ***How can you classify servo valves ?***

1. Mechanical type servo valve, and
2. Electrohydraulic servo valve,
   - (*i*) Single-stage servo valve,
   - (*ii*) Two-stage servo valve,
   - (*iii*) Jet pipe servo valve, and
   - (*iv*) Flapper jet servo valve.

6. ***Define the terms 'lap' and 'null' with respect to servo valves.***

✓ ***Lap*** is the length relationship between the metering lands to the spool and the port openings in the sleeve or body.

✓ ***Null*** is the relational condition between the spool and valve port where the valve supplies no control flow at zero load pressure drop.

7. ***What do you mean by zero lap servo valve ?***

The zero lap servo valve means that the edges of the spool lands are precisely made to line up with the metering ports in the valve sleeve.

8. ***Mention any four applications of hydromechanical servo valves.***

Hydromechanical servo valves are employed in steering devices (such as power steering system of automobiles), test and training devices, copying devices (such as machine tools), and heavy-duty mobile equipment.

9. ***How does an electrohydraulic servo valve differ from the hydromechanical servo valve ?***

In electrohydraulic servo valves, electrical signal is used to control the hydraulic output. But in mechanical servo valves, mechanical linkages are used for the same purpose.

10. ***Write few applications of electrohydraulic servo valves.***

The electrohydraulic servo valves are widely employed in more sophisticated control systems such as on tape-controlled machine tools, high-speed printing presses, press brakes, *etc.*

11. ***What are the advantages of electrohydraulic servo systems over hydromechanical servo systems ?***

The advantages of electrohydraulic servo systems over hydromechanical servo systems are as follows :

1. The electrohydraulic servo system can easily achieve the precision remote control of position, force, and speed of actuator.
2. They guarantee the higher flexibility of operation.
3. They ensure better control of fluid-compressibility, system-stiffness, and dynamic behaviour of load.
4. They also ensure correct ratio of force and speed that leads to higher energy conversion.

12. ***Differentiate between single-stage and two-stage servo valves.***

✓ In single-stage servo valves, the armature of the torque motor is connected directly to the valve spool, and therefore the input current will directly control the valve movement. But the two-stage configuration uses two stages—a pilot stage and a main stage—for the same purpose.

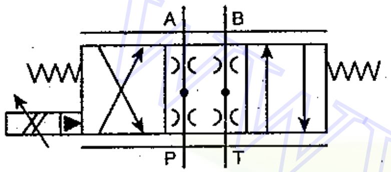
✓ Single-stage servo valves are limited only for small flow at low pressure, whereas two-stage servo valves can be used to handle large flow at high pressure.

13. ***What are proportional control valves ?***

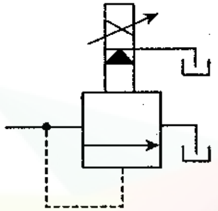
Similar to servo valves, proportional valves are also infinite variable position valves. They also use a variable force direct current solenoid to control the output from the main spool.

14. *Draw the graphic symbols for the following valves :*

(i) Four-way servo valve, and (ii) Proportional pressure relief valve.



(i) Graphic symbol of a four-way servo valve



(ii) Graphic symbol of a proportional pressure relief valve

CHAPTER 15 : LOGIC CONTROLS IN FLUID POWER SYSTEMS

1. *What is fluidics ?*

Fluidics is the technology that utilizes fluid flow phenomena in components and circuits to perform a wide variety of control functions.

2. *What advantages does fluidics offer ?*

1. Fluidic devices offer exceptional thermal and physical stability and ruggedness.
2. They are completely insensitive to radiation, even of extremely high loads.
3. They are not affected by severe vibration and shock.
4. They are not susceptible to wear and tear.

3. *At what pressures do fluidic devices function ?*

Normally fluidic devices function at pressures below 1 bar.

4. *Where are fluidic control systems preferred than other control systems ?*

Fluidic control systems are preferred over other control systems in areas subject to nuclear radiation, magnetic flux, temperature extremes, vibration, and mechanical shock.

5. *State the 'Coanda effect'.*

"When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."

6. *Name four fluidic devices.*

1. Bistable flip-flop,
2. Flip-flop with start-up preference,
3. SRT flip-flop,
4. OR/NOR gate.

7. *What is a bistable flip-flop ?*

A bistable flip-flop provides controlled assurance as to which of the two output ports will deliver the power stream. It is normally used as a memory device.

8. *What is a monostable device ?*

A monostable device is required to perform monostable function which is analogous to spring return function. In this device, when the control signal is removed, the device will switch back to the favoured output.

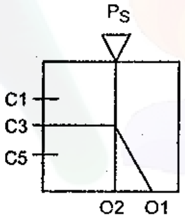
9. *When do you use a flip-flop with start-up preference ?*

A flip-flop with start-up preference is used in applications where a specific output is required when the power supply is first turned ON and all controls are OFF.

10. *What is the use of truth table in logic devices ?*

A truth table helps to describe the functioning of that particular logic device.

11. *Give the symbol and truth table for fluidic OR/NOR gate.*

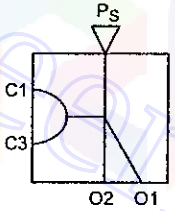


		OR	NOR
C1	C3	O1	O2
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

Symbol *Truth table*

OR/NOR gate

12. *Give the symbol and truth table for the fluidic AND/NAND gate.*

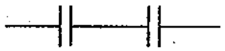


		AND	NAND
C1	C3	O1	O2
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

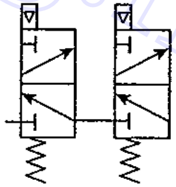
Symbol *Truth table*

AND/NAND gate

13. *Draw the equivalent electrical and pneumatic symbols for AND gate function.*



(a) Electrical equivalent



(b) Pneumatic equivalent

14. ***What is Boolean algebra ? Write its two functions relative to fluid power systems.***

✓ Boolean algebra is an 'algebra of logic'. This is the algebra of proportions where only two possibilities – true or false – are allowed.

✓ Boolean algebra provides the following two functions :

1. It provides a means by which a logic circuit can be reduced to its simplest form.
2. It allows for the quick synthesis of a circuit that is to perform desired logic operations.

15. ***What is a fluid sensor ?***

A fluid sensor is a device that senses a change in some parameter and as a result causes a related change in another parameter that can be recognized and interpreted.

16. ***Name four fluid sensors that are used in fluid power systems.***

1. Back-pressure sensor,
2. Cone-jet proximity sensor,
3. Interruptible-jet sensor, and
4. Contact sensing.

17. ***What is meant by the term 'contact sensing' ?***

Contact sensing is nothing but the sensing of objects by physical contact. It can be achieved by using a device called a limit valve or limit switch.

18. ***What are moving-part logic devices ?***

Moving-part logic (MPL) devices are miniature valve-type devices that perform switching operations in fluid logic systems by the action of internal moving parts.

19. ***Name three ways in which MPL devices can be actuated.***

The MPL devices can be actuated by means of (*i*) mechanical displacement, (*ii*) electric voltage, or (*iii*) Fluid pressure.

20. ***What are the distinctive features that differentiates MPL devices from fluidic devices.***

1. Very small in size and hence occupies less space.
2. Very fast response time.
3. Can be readily interfaced with electric and electronic circuits.
4. Longer life of elements.

21. ***Name few applications of MPL devices.***

The MPL devices are well-suited for a wide range of applications in biomedical, environmental test equipment, textile machines, packaging machinery, computerised industrial automation, and portable systems.

22. ***What is a PLC ?***

A programmable logic controller (PLC) is a user-friendly electronic computer designed to perform logic functions such as AND, OR, or NOT for controlling the operation of industrial equipment and processes.

23. ***How does a PLC differ from a general-purpose computer ?***

1. PLCs are rugged and designed to withstand vibrations, temperature, humidity, and noise.
2. The interfacing for inputs and outputs is inside the controller.
3. They are easily programmed and have an easily understood programming language. Programming is primarily concerned with logic and switching operations.

24. ***List any four advantages that PLCs provide over electromechanical relay control systems.***

1. PLCs are more reliable and faster in operation.
2. They are smaller in size and can be more readily expanded.
3. They require less electrical power.
4. They have very few hardware failure when compared to electromechanical relays.

25. ***List three major units of a PLC.***

1. Central processing unit (CPU).
2. Programmer/monitor (PM), and
3. Input/output module (I/O).

26. ***What is the function of the CPU in a PLC ?***

The CPU (*i*) receives input data from various sensing devices, (*ii*) executes the stored program, and (*iii*) delivers corresponding output signals to various load control devices.

27. ***What is the purpose of the I/O module in a PLC ?***

The purpose of the I/O module is to transform the various signals received from or sent to the fluid power interface devices.

CHAPTER 16 : FLUID POWER CIRCUITS : FAILURE AND TROUBLESHOOTING

1. ***List four basic requirements on which the life of the fluid power systems depend ?***

The four basic requirements are :

(*i*) Properly installed equipments,

(*ii*) Properly trained personnel,

(*iii*) Planned preventive maintenance, and

(*iv*) Efficient troubleshooting.

2. ***List any four common types of faults that can be found in hydraulic systems.***

1. Reduced speed of travel of machine tool elements.
2. Slow response to control.
3. Excessive loss of system pressure.
4. Excessive leakage in the system.

3. ***List any four common causes of hydraulic system breakdown.***

1. Inadequate supply of oil in the reservoir.
2. Clogged or dirty oil filters.
3. Leaking seals.
4. Loose inlet lines that cause the pump to take in air.

4. ***What does the term troubleshooting refer ?***

The term troubleshooting refers to an organised and systematic study of the problem and a logical approach to the difficulty faced in a system.

5. ***What is the purpose of a tree-branching chart ?***

A tree-branching chart is a fault finding chart which can be used to simplify the complex fault finding process in a fluid power circuit. This chart helps the maintenance personnel in developing a logical and rapid approach to fault diagnosis.

6. ***List any four common types of pump faults.***

1. Pump may deliver insufficient or no oil.
2. Pump may make more noise.
3. Pump may develop unstable or zero pressure.
4. Pump oil may get overheated.

7. ***If a pump is delivering insufficient or no oil, what are all the possible causes and also give remedies for them.***

Probable Causes	Remedies
1. Wrong direction of shaft.	Must be reversed immediately to prevent seizure.
2. Pump shaft turning too slowly to prime itself.	Check minimum speed recommendation and momentarily increase rpm, to rectify.
3. Clogged strainer or suction pipeline.	Clean strainer or suction pipeline. Remove foreign matter.
4. Air leak in suction line.	Add oil and check oil level in reservoir. Check for leaks and repair.

8. ***List any four causes for a pump making more noise.***

1. Misalignment of pump and prime mover.
2. Strainer capacity insufficient.
3. Air remains in pump casing.
4. Small size of suction pump.

9. ***List any two types of faults that can be found in each of the following hydraulic valves : (a) Directional control valve, and (ii) Flow control valve.***

Faults in a DC valve may be :

1. Faulty or incomplete shifting, or
2. Cylinder creeping or drifting.

Faults in a flow control valve may be :

1. Variation in feed, or
2. External leakage.

10. ***If a hydraulic motor does not provide the proper speed and torque, what could be the possible causes for it ?***

Probable causes are :

1. System overload, relief valve adjustment not set high enough.
2. Relief valve sticking open.
3. Free recirculation of oil to reservoir.
4. Pump not delivering sufficient volume or pressure.

11. ***What will you do to reduce/prevent excessive heating of oil in a hydraulic system ?***

Remedial actions are :

1. Follow manufacturer's instructions while trying to reassemble.
2. Use artificial cooling.
3. Provide large reservoir or install cooler.
4. Check and repair the leaking check valves and relief valves in the pump.

12. ***List any two types of faults that can be found in each of the components of a FRC unit.***

Faults in a filter :

1. Excessive pressure drop through filter.
2. Contaminants carried through the filter.

Faults in a regulator :

1. Air often escaping from vent hole.
2. Chatter and vibration.

Faults in a lubricator :

1. Oil not delivered from the lubricator.
2. Delayed oil delivery.

13. ***If an air cylinder produces erratic cylinder action, identify the probable causes and also give remedies for them.***

Probable Causes	Remedies
1. Valve sticking or binding.	(*a*) Check for dirt or gummy deposits. (*b*) Check for worn parts.
2. Cylinder sticking or binding.	(*a*) Check for overtightened packing on rod seal or piston. (*b*) Check for misalignment or worn parts.

14. ***List the probable causes for the problem of leakage of compressed air in pneumatic systems.***

1. Loose joints, fittings or glands.
2. Ruptured pipes and hoses.

□□

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Anna University
Question Papers

B.E./B.Tech. Degree Examination, April/May 2005

Sixth Semester – Mechanical Engineering

ME 341 – HYDRAULIC AND PNEUMATIC CONTROLS

(Common to Mechatronics Engineering)

Time : Three hours **Maximum : 100 marks**

Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. ***Name any four desirable characteristics of hydraulic pumps.***

   (*i*) Pumps should provide safe and maximum system working pressure.

   (*ii*) They should have high volumetric and overall efficiency.

   (*iii*) They should be compact and also have higher power-to-weight ratio.

   (*iv*) They should possess the variable displacement control.

2. ***Name any four drawbacks of fluid power systems.***

   1. Hydraulic fluid leakage poses many problems to the operations as well as operators.
   2. Flammable hydraulic fluids may pose fire hazards thus limiting the upper level of working temperature.
   3. Hydraulic elements require special treatments to protect them against rust, corrosion, dirt, *etc.* Otherwise the contaminated elements may impair the system operation.
   4. Hydraulic fluids may pose problems if it disintegrates due to ageing and chemical deterioration.

3. ***State the need for synchronization of hydraulic cylinders.***

   There are many industrial applications which require nearly perfect synchronization of movement of two or more cylinders in order to complete some phase of operation. Synchronization is required where exact movement is required at both ends of a span, such as on rolling equipment, power shears, power brakes, large presses, *etc.*

4. ***What is a hydraulic fuse ?***

   A hydraulic fuse, analogous to an electric fuse, prevents hydraulic pressure from exceeding an allowable value in order to protect circuit components from damage.

5. ***What are the functions of reservoir ?***

   Reservoirs not only provide a storage facility for the liquid but can also serve to separate entrained air, remove contaminants, and dissipate heat from the liquid.

6. ***What is two-way valve ?***

   Two-way valve contains two ports. Two-way valves are generally used as check and shut-off valves.

7. ***What is the function of bleed off circuits ?***

   Bleed-off circuit is used to control the flow of fluid in both directions of flow or on a specific line and limits speed in only one direction of the cylinder travel.

8. ***What is meant by interlock contacts ?***

Interlock contacts are nothing but relay contacts. Relays are switches whose contacts open or close when their corresponding coils are energized. The relay contacts provide interlock capability, which prevents the accidental energizing of two solenoids at the opposite ends of a valve spool. This safety feature can prevent the burn out of one or both of these solenoids.

9. ***Mention any two roles of pneumatic systems in low cost automation.***

Pneumatic systems are popularly used for low cost automation (LCA) applications due to their low cost, ease of fabrication, and safe operation.

10. ***What do you understand by single shot sequencing ?***

By sequencing a number of cylinders, various machining and tooling operations may easily be obtained in a machine. By using sequencing, the cylinders can be actuated one after another in sequences like clamping, drilling, unclamping, *etc.*

Part B – (5 × 16 = 80 marks)

(i) A double acting cylinder is hooked up in regenerative circuit as shown in Fig.1. The relief valve setting is 105 bars. The piston area is 130 cm² and the rod area is 65 cm². If the pump flow is 0.0016 m³/s, find the cylinder speed and load carrying capacity for (1) Extending stroke, (2) Retracting stroke. **(12)**

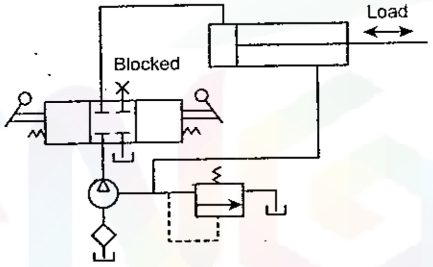


Fig. 1

Given Data : P = 105 bars; $A_p = 130$ cm²; $A_r = 65$ cm²; $Q_P = 0.0016$ m³/s.

☺ ***Solution : (1) Cylinder speed and load carrying capacity for extending stroke :***

$$\text{Cylinder speed, } (v_p)_{ext} = \frac{Q_P}{A_r} = \frac{0.0016}{65 \times 10^{-4}} = \mathbf{0.246\ m/s} \quad \textbf{Ans.}$$ ☜

$$\text{Load carrying capacity, } (F_{load})_{ext} = P \cdot A_r = (105 \times 10^5)(65 \times 10^{-4})$$
$$= \mathbf{68.25\ kN} \quad \textbf{Ans.}$$ ☜

(2) Cylinder speed and load carrying capacity for retracting stroke :

$$\text{Cylinder speed, } (v_p)_{ret} = \frac{Q_P}{A_p - A_r} = \frac{0.0016}{(130 \times 10^{-4} - 65 \times 10^{-4})}$$
$$= \mathbf{0.246\ m/s} \quad \textbf{Ans.}$$ ☜

$$\text{Load carrying capacity, } (F_{load})_{ret} = P(A_p - A_r)$$
$$= (105 \times 10^5)[130 \times 10^{-4} - 65 \times 10^{-4}]$$
$$= \mathbf{68.25\ kN} \quad \textbf{Ans.}$$ ☜

(ii) ***Which kind of accumulator operates at constant pressure ? How can the pressure be changed ?*** **(4)**

✓ Weight-loaded (or dead-weight) accumulator operates at constant pressure.

✓ The pressure can be changed by changing the dead-weight of the accumulator.

12. ***(a) (i) The power and load carrying capacity of a hydraulic cylinder (Extension) are 10 kW and 20,000 N respectively. Find the piston velocity during extension.*** **(4)**

For the above system if the area of piston side and rod side is 2 : 1, find the retraction speed. The pump delivers oil at 0.2 m³/min. **(4)**

Given Data : $(\text{kW Power})_{ext} = 10$ kW; $F_{ext} = 20{,}000$ N = 20 kN; $A_p/A_r = 2$ or $A_p = 2\,A_r$; $Q_{in} = 0.2$ m³/min = (0.2/60) m³/sec.

☺ ***Solution : To find the piston velocity during extension :***

We know that $\quad \text{Power (kW)} = v_p\,(\text{m/s}) \times F\,(\text{kN})$

$$\therefore \quad (v_p)_{ext} = \frac{(\text{kW power})_{ext}}{F_{ext}} = \frac{10}{20} = \mathbf{0.5\ m/s} \quad \textbf{Ans.}$$ ☜

To find the retraction speed : First let us find A_p and A_r.

$$\text{We know that,} \quad A_p = \frac{Q_{in}}{(v_p)_{ext}} = \frac{(0.2/60)}{0.5} = 6.666 \times 10^{-3}\ \text{m}^2$$

$$\therefore \quad (v_p)_{ret} = \frac{Q_{in}}{A_p - A_r} = \frac{Q_{in}}{A_p - 0.5\,A_p} = \frac{Q_{in}}{0.5\,A_p} \quad [\because A_p = 2\,A_r\text{, given}]$$

$$\text{or} \quad (v_p)_{ext} = \frac{(0.2/60)}{0.5\,(6.666 \times 10^{-3})} = \mathbf{1\ m/s} \quad \textbf{Ans.}$$ ☜

(ii) ***What are the factors to be selected in selection of a pump for automobile lift ?*** **(8)**

Ans. Refer Chapter 5, Section 5.20.

[OR]

(b) (i) How will you measure the pump performance ? Explain each with suitable examples. **(8)**

Ans. Refer Chapter 5, Section 5.17.

(ii) ***A pump has a displacement volume of 98.4 cm³. It delivers 0.00152 m³/s of oil at 1000 rpm and 70 bars. If the prime mover input torque is 124.3 N-m (1) What is the overall efficiency of the pump ? (2) What is the theoretical torque required to operate the pump ?*** **(8)**

Given Data : $V_D = 98.4$ cm³ = 98.4×10^{-6} m³; $Q_A = 0.00152$ m³/s; N = 1000 rpm; P = 70 bar = 70×10^5 N/m²; $T_A = 124.3$ N-m.

☺ ***Solution :*** $\omega = 2\pi N/60 = 2\pi\,(1000)/60 = 104.72$ rad/s.

(1) To find overall efficiency of the pump (η_o) :

We know that, $$\eta_o = \frac{P \times Q_A}{T_A \cdot \omega} \times 100$$

$$= \frac{(70 \times 10^5)\,(0.00152)}{124.3 \times 104.72} \times 100 = \mathbf{81.74\%} \quad \textbf{Ans.}$$

(2) To find the theoretical torque required to operate the pump (T_T) :

We know that, $$T_T = \frac{V_D \times P}{2\pi}$$

$$= \frac{(98.4 \times 10^{-6})\,(70 \times 10^5)}{2\pi} = \mathbf{109.62\ N\text{-}m} \quad \textbf{Ans.}$$

13. (*a*) (*i*) ***Draw and explain hydraulic cylinder sequence circuit.*** **(8)**

Ans. Refer Chapter 13, Section 13.8.

(*ii*) ***Explain the working principle of a fail safe circuit with overload protection.*** **(8)**

Circuit : The fail safe circuit that protects the system from overload is shown in Fig.2.

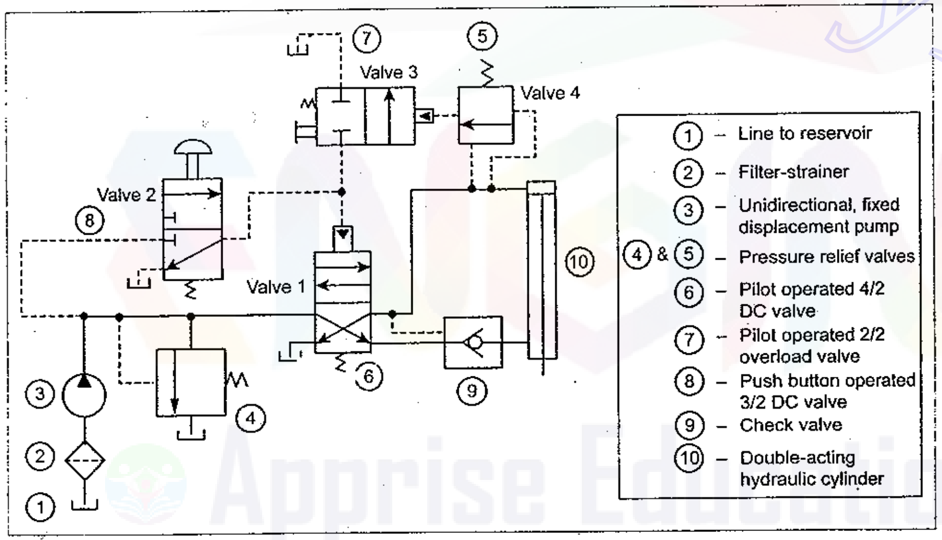

⑦
⑤
Valve 3
Valve 4
Valve 2
⑧
Valve 1
⑩
⑥
⑨
③
④
②
①
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ & ⑤ – Pressure relief valves
⑥ – Pilot operated 4/2 DC valve
⑦ – Pilot operated 2/2 overload valve
⑧ – Push button operated 3/2 DC valve
⑨ – Check valve
⑩ – Double-acting hydraulic cylinder

Fig. 2. Fail-safe circuit with overload protection

Operation : Push-button 3/2 valve (*i.e.*, valve 2) controls the 4/2 DC valve (*i.e.*, valve 1). When overload valve (*i.e.*, valve 3) is shifted to its left mode, it drains the pilot line of valve 1. If the cylinder experiences excessive resistance during the extension stroke, sequence valve 4 pilot-actuates overload valve 3. This drains the pilot line of valve 1, causing it to return to its spring-offset mode. If an operator operates push button valve 2, nothing will happen unless overload valve 3 is manually shifted to its blocked port configuration. Thus the system components are protected against overload during its extension stroke.

[OR]

(*b*) (*i*) ***Draw and explain the hydraulic circuit used in milling machine.*** **(8)**

Ans. Refer Chapter 13, Section 13.6.

(*ii*) ***Discuss the applications of hydraulic circuits in press and planner.*** **(8)**

Ans. Refer Chapter 13, Section 13.7.

14. (*a*) (*i*) ***A rotary vane air motor has a displacement volume of 80 cm³/rev and operates at 1750 rpm using 700 kPa gauge pressure air. Calculate the standard m³/min rate of consumption and kW power output of the motor. Assume the temperature remains constant.*** **(10)**

Given Data : $V_D = 80$ cm³/rev ; $N = 1750$ rpm; $P = 700$ kPa.

☺ ***Solution :*** It may be noted that the equations for determining the output torque and power for air motors are identical to those used for hydraulic motors.

(1) To find m³/min rate of air consumption :

We know that, Flow rate of air motor, $$Q_2\ (\text{m}^3/\text{min}) = V_D\ (\text{m}^3/\text{rev}) \times N\ (\text{rpm})$$

$$= (80 \times 10^{-6})\ 1750$$

$$= 0.14\ \text{m}^3/\text{min}$$

$\therefore$ Standard air consumption, $$Q_t = Q_2 \left(\frac{P_2}{P_1}\right)\left(\frac{T_1}{T_2}\right)$$

Here,

P_2 = 700 kPa gauge = 700 + 101 = 801 kPa absolute

P_1 = Standard air = 101 kPa absolute

$T_1 = T_2$

$$\therefore \quad Q_1 = 0.14\left(\frac{801}{101}\right) = \mathbf{1.11\ m^3/min} \quad \textbf{Ans.}$$

(2) To find kW power output of motor :

$$\text{kW Power} = \frac{V_D\ (\text{m}^3/\text{rev}) \times P\ (\text{kPa}) \times \omega\ (\text{rad/s})}{6.28}$$

$$= \frac{(80 \times 10^{-6})\,(700) \times \left(\dfrac{2\pi \times 1750}{60}\right)}{6.28} = \mathbf{1.634\ kW} \quad \textbf{Ans.}$$

(ii) Describe the function of an air pressure regulator with neat sketch. **(6)**

Ans. Refer Chapter 11, Section 11.8.

[OR]

(b) (i) Explain with neat block diagram, an air pilot control circuit for a double-acting cylinder. **(8)**

Ans. Refer Chapter 13, Section 13.17.

(ii) Describe any one of the electro-hydraulic circuits used in robotic systems. **(8)**

Ans. Refer Chapter 13, Section 13.22.

15. ***(a) (i) What are the advantages of programmable logic controller ?*** **(5)**

Ans. Refer Chapter 15, Section 15.8.4.

(ii) Explain the working principle of a PLC with a neat block diagram. **(7)**

Ans. Refer Chapter 15, Section 15.12.

(iii) How does a PLC differ from microprocessor ? **(4)**

Ans. Refer Chapter 15, Section 15.8.3.

[OR]

(b) (i) Describe various selection criteria for pneumatic components. **(6)**

The various pneumatic components for a pneumatic system are selected based on the following criteria :

1. Work output required.
2. Maximum fluid pressure used in the system.
3. Speed of operation.
4. Life of the system.

(ii) Explain the application of hydraulic and pneumatic system for low cost automation with suitable examples. **(6)**

Ans. This question is beyond the scope of the 2004 regulation syllabus.

(iii) Write a note on power packs. **(4)**

Power pack consists of a pump, electric motor, reservoir and associated valving assembled to one unit to supply pressurized fluid. They are relatively small in size and provide functions of pressure, direction and flow control within the basic package.

□□

B.E./B.Tech. Degree Examination, November/December 2005
Sixth Semester – Mechanical Engineering
ME 341 – HYDRAULIC AND PNEUMATIC CONTROLS
(Common to Mechatronics Engineering)

Time : Three hours **Maximum : 100 marks**

Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. ***Define fluid power.***

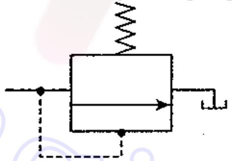
Fluid power is defined as the technology that deals with the generation, control, and transmission of power using pressurized fluids.

2. ***How do you classify direction control valves ?***

Based on the number of ports present, the DCVs are classified as :

(*i*) Two way valves,
(*ii*) Three way valves, and
(*iii*) Four way valves.

3. ***Draw the symbol for pressure relief valve.***



4. ***What is the purpose of regenerative circuit ?***

The regenerative circuit is used to speed up the extending speed of a double-acting hydraulic cylinder.

5. ***What is the function of an accumulator ?***

An accumulator is a device used to store the energy of liquid under pressure and make this energy available as a quick secondary source of power to hydraulic machines.

6. ***How do you select hydraulic pipes for a hydraulic system ?***

The hydraulic pipes are selected based on the following factors :

1. System pressure,
2. Pressure pulses,
3. Velocity of fluid flow,
4. Fluid compatibility, and
5. Environmental conditions.

7. ***What is a ladder diagram ?***

The ladder diagram is a representation of hardware connections between switches, relays and solenoids, *etc.*, which constitute the basic components of an electrical control system. The left leg of the ladder connected to the power and the right to the ground.

8. ***What is air-oil intensifier ?***

Air-over-oil intensifier is used for driving a cylinder over a large distance at a low pressure and then over a small distance at high pressure (such as in punch press application).

9. ***What is a power pack ?***
Power pack consists of a pump, electric motor, reservoir and associated valving assembled to one unit to supply pressurized fluid. They are relatively small in size and provide functions of pressure, direction and flow control within the basic package.

10. ***How do microprocessors differ from PLCs ?***
The advantages of PLCs over microprocessors are given below :

1. PLCs are rugged and designed to withstand vibrations, temperature, humidity and noise.
2. The interfacing for inputs and outputs is inside the controller.
3. They are easily programmed and have an easily understood programming language.

Part B – (5 × 16 = 80 marks)

11. *(i) When designing a hydraulic circuit, enunciate the important factors that must be taken into account ?* **(8)**
Ans. Refer Chapter 13, Section 13.2.3.

(ii) What are main parameters affecting the performance of a pump ? Briefly discuss. **(8)**
Ans. Refer Chapter 5, Section 5.17.

12. *(a) (i) How do you classify pumps ? Explain with suitable sketch the working of vane pump ?* **(10)**
Ans. Refer Chapter 5, Sections 5.3 and 5.11.

(ii) Explain the working of four way two position direction control valve. **(6)**
(ii) ***Ans.*** Refer Chapter 7, Section 7.10.1.

[OR]

(b) (i) With a sketch describe the construction and operation of a pressure compensated flow control valve. **(10)**
Ans. Refer Chapter 7, Section 7.22.

(b) (ii) A pump has a displacement volume of 0.0819 × 10^{-3} m^3. It delivers 0.0758 m^3/min at 1000 rpm at 67 bar. If the prime mover input torque is 100 N-m.

(1) What is overall efficiency ?

(2) What is the theoretical torque required to operate the pump ? **(8)**

Given Data : $V_D = 0.0819 \times 10^{-3}$ m^3; $Q_A = 0.0758$ m^3/min; N = 1000 rpm; P = 67 bar = 67×10^5 N/m^2; $T_A = 100$ N-m.

☺ ***Solution :*** $\omega = 2\pi N/60 = 2\pi\,(1000)/60 = 104.72$ rad/s

(1) To find the overall efficiency (η_o) :

$$\eta_o = \frac{P \times Q_A}{T_A \cdot \omega} \times 100 = \frac{(67 \times 10^5)\,(0.0758/60)}{100 \times 104.72} \times 100 = \mathbf{80.83\%}$$
Ans. ☜

(2) To find the theoretical torque required to operate the pump (T_T) :

$$T_T = \frac{V_D \times P}{2\pi} = \frac{(0.0819 \times 10^{-3})\,(67 \times 10^5)}{2\pi} = \mathbf{87.33\ N\text{-}m}$$
Ans. ☜

13. *(a) (i) Describe an hydraulic circuit for synchronising two cylinders with flow control valves.* **(8)**
Ans. Refer Chapter 13, Section 13.10.

(ii) Design a hydraulic sequence circuit for a milling machine with one cylinder for operating the power vice jaw and the other for controlling the cutler travel. **(8)**
Ans. Refer Chapter 13, Section 13.8.

[OR]

(b) (i) A press cylinder has to exert a force to lift the crosshead and tooling. The cylinder is rigidly fixed by front flange and the load is pivoted and fully guided. Maximum thrust from the press is 260 kN with a stroke of 1.4 m. Determine the size of suitable cylinder. The system working pressure should not exceed 200 bar. **(8)**

Given Data : F = 260 kN; Stroke = 1.4 m; Maximum system working pressure = 200 bar.

☺ ***Solution :*** The piston rod in a hydraulic cylinder will act as a strut when it is subjected to a compressive load or when it exerts a thrust. Therefore the rod must be of sufficient diameter to prevent buckling.

So the suitable piston rod diameter to withstand buckling can be calculated using the following Euler's strut formula :

$$K = \frac{\pi^2 E I}{L^2}$$

where K = Bucking load in N,
= Maximum load (F) × Factor of safety (S),
E = Modulus of elasticity in N/m^2,
= 2.1×10^{11} N/m^2 for steel.
I = Moment of inertia of piston rod (m^4), and
= $\left(\frac{\pi}{64}\right) d^4$, here d = Diameter of piston rod,
L = Equivalent buckling length (m),
= $\frac{\text{Cylinder stroke}}{\sqrt{2}}$, for the cylinder mounting conditions.

∴ Buckling load, K = F × S = $(260 \times 10^3)\,3$ [∵ Factor of safety is assumed as 3]
= 780 kN

Equivalent bucking length, $L = \frac{\text{Cylinder stroke}}{\sqrt{2}} = \frac{1.4}{\sqrt{2}} = 0.99$ m

Now applying Euler's formula, we get

$$K = \frac{\pi^2 E I}{L^2}$$

or $$780 \times 10^3 = \frac{\pi^2 (2.1 \times 10^{11}) I}{(0.99)^2}$$

or $$I = 3.76 \times 10^{-7} \text{ m}^4 = \frac{\pi}{64} d^4$$

or Piston rod diameter, $d = 0.053$ m or **53 mm** **Ans.** ☜

Dynamic thrust = Maximum allowable pressure × Area of piston

$$\text{Piston area} = \frac{\text{Thrust}}{\text{Maximum allowable pressure}}$$

$$= \frac{260 \times 10^3}{200 \times 10^5} = 0.013 \text{ m}^2$$

or $$\text{Piston area} = \frac{\pi}{4} D^2 = 0.013 \text{ m}^2$$

or Piston diameter, $D = 0.1286$ m or **128.6 mm** **Ans.** ☜

(ii) Briefly describe the construction of any two types of accumulators. (8)

Ans. Refer Chapter 8, Sections 8.3 and 8.4.

14. *(a) (i) Describe various pneumatic actuators with neat sketches.* (4)

Ans. Refer Chapter 12, Section 12.10.3.

(ii) Develop an electropneumatic circuit for the following sequence $A^+ B^+ A^- B^-$ where A and B stand for cylinders, (+) indicates extension and (–) retraction of cylinders. (12)

Ans. Refer Chapter 13, Example 13.3.

[OR]

(b) Design an electrohydraulic circuit for the following sequence : $A^+ B^+ B^- A^-$ where A and B stand for cylinders, + indicates extension and – retraction. Incorporate provision for auto-manual selector and emergency stop. (16)

Ans. Refer Chapter 13.

15. *(a) (i) What are PLCs ? Explain their application in low cost automation.* (8)

Ans. Refer Chapter 15, Section 15.8.

(ii) Give the procedure of the cascade method of designing sequencing circuits. (8)

Ans. Refer Chapter 13, Section 13.26.1.

[OR]

(b) (i) List out various operating problems associated with pumps and valves and the corresponding possible causes and suitable remedy for each problem. (8)

Ans. Refer Chapter 16, Section 16.2.4.

(ii) Enunciate various criteria for the selection of pneumatic components. (8)

Ans. Refer Q.No. 13, Section 13.14.

□□

B.E./B.Tech. Degree Examination, May/June 2006

Sixth Semester – Mechanical Engineering (Regulation 2001)

ME 341 – HYDRAULIC AND PNEUMATIC CONTROLS

Time : Three hours **Maximum : 100 marks**

Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. *Define viscosity and bulk modulus of a hydraulic fluid.*

✓ ***Viscosity*** may be defined as the shearing force required to move two plane surfaces relative to one another with a film of fluid between them.

✓ ***Bulk modulus*** is the measure of compressibility of a fluid. It is the reciprocal of compressibility.

2. *Give the expression used to determine the wall thickness and inside diameter of a hydraulic conductor.*

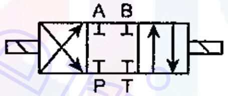
$$\text{Wall thickness, } t = \frac{D_o - D_i}{2}$$

$$\text{and Inside diameter of a hydraulic conductor, } D_i = \sqrt{\frac{4A}{\pi}}$$

where D_o = Conductor outside diameter, and

A = Required pipe flow area.

3. *Give the hydraulic symbol for a 3-position, 4-way, closed centre solenoid operated direction control valve.*

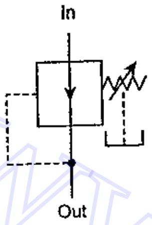


4. *What is the difference between pilot operated and direct operated pressure relief valve?*

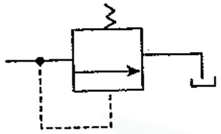
Direct operated pressure relief valves are used where the flow rate and the system pressure are reasonably smaller or there is not much variation in system pressure or flow rate. Whereas for a larger flow rate and higher pressure, pilot operated pressure relief valves are used. The great advantage of pilot valve is that it can be kept spatially separated from the main valve.

5. *Distinguish between the pressure reducing valve and pressure relief valve by giving the graphical symbols.*

Pressure reducing valve maintains a prescribed reduced pressure at its outlet regardless of the valve inlet pressure. But the pressure relief valve limits the maximum pressure that can be applied to the part of the system to which it is connected.



Pressure reducing valve



Pressure relief valve

6. ***What is "meter-in" circuit? What is its limitation?***

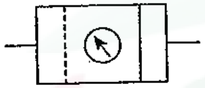
✓ In 'meter-in' circuit, the flow control valve is placed in the line leading to the inlet port of the cylinder.

✓ *Limitation:* There will be a drop in oil pressure fed to the cylinder due to throttling effect of the flow control valve. Hence for a low pressure system, meter–in circuit is not preferred.

7. ***What is a relay?***

Relay is nothing but electrically operated switches. It offers simple ON/OFF switching action in response to a signal issued by a control system.

8. ***Give the standard graphical symbol for FRL unit.***



9. ***Give the Harris formula used to determine the pressure drop in pipes for pneumatic circuits.***

$$p_f = \frac{0.1025\ L\ Q^2}{3600\ (CR) \times d^{5.31}}$$

where p_f = Pressure loss (psi),
L = Length of pipe (ft),
Q = Flow-rate (scfm),
CR = Compression ratio = Pressure in pipe/atm pressure, and
d = Inside diameter of pipe (in).

10. ***What is a microprocessor?***

Microprocessor is the central processing unit (CPU) of a micro-computer. It is the heart of the microcomputer. It is a semiconductor device. It includes arithmetic and logic unit, register arrays, and control circuits on a single chip.

Part B – (5 × 16 = 80 marks)

11. *(i) Discuss the factors to be considered in the selection of hydraulic fluids.* (8)

Ans. Refer Chapter 2, Section 2.23, Page No.2.12.

(ii) Explain the factors which affect the selection of pumps and discuss in detail the classification and performance features of different types of hydraulic pumps. (8)

Ans. Refer Chapter 5, Sections 5.3, 5.16 & 5.19, Page Nos. 5.3, 5.24 & 5.31.

12. ***(a) (i) Explain a hydraulic press circuit which employs double pump unloading principle.*** *(8)*

Circuit: The hydraulic press circuit employing double pump unloading principle is shown in Fig.1.

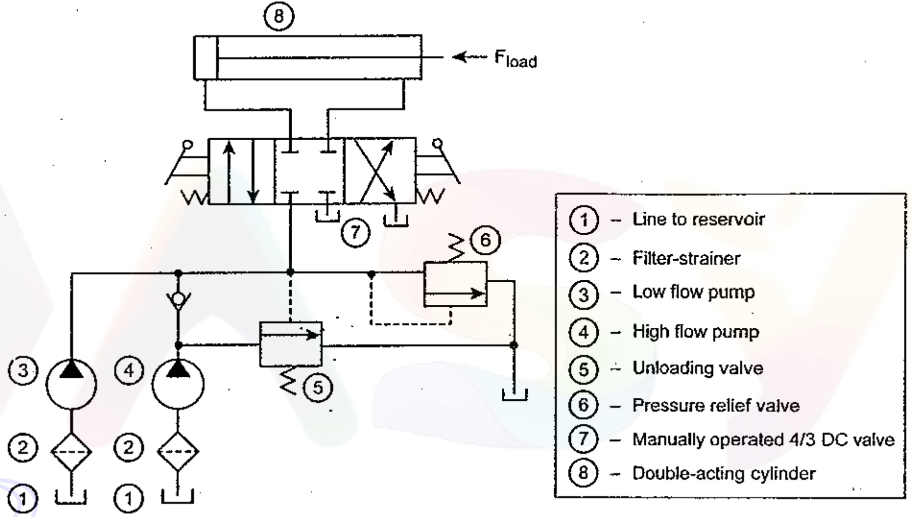


Fig.1. Double-pump hydraulic press circuit

Operation: When the pressing/punching operation starts, the increased pressure opens the unloading valve to unload the low-pressure pump. When the DC valve is in its spring-centered mode, the relief valve protects the high-pressure pump from overpressure at the end of the cylinder stroke. During the punching operation, the check valve protects the low-pressure pump from high pressure.

(ii) Draw a single cylinder continuous reciprocation circuit using suitable components and give the specifications of them. *(8)*

Ans. Refer Chapter 13, Section 13.9, Page No.13.9.

[OR]

(b) (i) Give any two application circuits employing accumulator for different purposes.

Ans. Refer Chapter 8, Section 8.11, Page No.8.11. *(8)*

(ii) Develop a two handed safety circuit for the operation of a press and explain. *(8)*

Ans. Refer Chapter 13, Section 13.13, Page No.13.15.

13. ***(a) (i) A hydraulic pump delivers oil at 60 bar, 120 lpm into a circuit laid on a horizontal plane. There are 4 elbows (k = 0.75), one globe valve fully open (k = 10) and a direction control valve (pressure drop = 3 bar) with the inside diameter of the pipe as 30 mm. The total length of the straight run pipe is 20 m and the specific gravity of the oil is 0.9. The kinematic viscosity of the oil is 0.0001 m²/s. Determine the pressure in bar at the exit point of the pipe.*** *(10)*

Given Data: $P = 60$ bar; $Q = 120$ lpm; $D = 30$ mm; $L = 20$ m; $S = 0.9$; $\nu = 0.0001\ m^2/s$.

☺ ***Solution:***

$$\text{Velocity, } V = \frac{Q}{A} = \frac{(120 \times 10^{-3}/60)\ m^3/s}{\left[\frac{\pi}{4}(30 \times 10^{-3})^2\right]\ m^2} = 2.83\ m/s$$

$$\text{Reynold's number, } Re = \frac{VD}{\nu} = \frac{(2.83)(30 \times 10^{-3})}{0.0001} = 849$$

Since $Re < 2000$, therefore the flow is laminar.

∴ Head losses in laminar flow in the pipe is given by

$$(H_L)_{pipe} = \frac{64}{Re}\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

$$= \frac{64}{849}\left(\frac{20}{30 \times 10^{-3}}\right)\left(\frac{2.83^2}{2 \times 9.81}\right) = 20.51\ m$$

$$\text{Head loss in valves and Fittings} = (H_L)_{elbows} + (H_L)_{globe} + (H_L)_{DCV}$$

$$= \left[4 \times K_1\left(\frac{V^2}{2g}\right)\right] + \left[K_2\left(\frac{V^2}{2g}\right)\right] + [\Delta P / \omega_{oil}]$$

$$= \left[4 \times 0.75\left(\frac{2.83^2}{2 \times 9.81}\right)\right] + \left[10 \times \left(\frac{2.83^2}{2 \times 9.81}\right)\right] + \left[\frac{3 \times 10^5}{0.9 \times 9810}\right]$$

$$= 1.225 + 4.082 + 33.98 = 39.28\ m$$

$$\therefore \text{Total head loss} = 20.51 + 39.28 = 59.79\ \text{m of oil}$$

or

$$\text{Equivalent pressure drop, } \Delta P = \omega_{oil} \times (H_L)_{total} = (0.9 \times 9810)\ 59.79$$

$$= 527885.9\ N/m^2 \text{ or } 5.28\ \text{bar}$$

$$\therefore \text{Pressure at the exit point of the pipe} = \text{Inlet pressure} - \text{Total pressure drop}$$

$$= 60 - 5.28 = \mathbf{54.72\ bar}$$ **Ans.** ☜

(ii) Explain how the pressure relief valve and its variants could be used for unloading applications. *(6)*

Ans. Refer Chapter 7, Section 7.15, Page No.7.21.

[OR]

(b) (i) List the need and application of synchronising circuits. *(4)*

Ans. Refer Chapter 13, Section 13.10, Page No.13.10.

(ii) With simple sketches, explain the various types of synchronising circuits. *(12)*

Ans. Refer Chapter 13, Section 13.10.1, Page No.13.10.

14. ***(a) (i) Draw a neat sketch of pneumatic filter and explain its construction and working. Also give the graphical symbol.*** *(6)*

Ans. Refer Chapter 11, Section 11.7, Page No.11.10.

(ii) Develop a continuous single cylinder reciprocation circuit for pneumatic system using limit switches and relays. *(10)*

Ans. Refer Chapter 9, Section 9.6, Page No.9.10.

[OR]

(b) (i) Draw a neat sketch of an electro-hydraulic for sequencing drilling and clamping cylinders. *(10)*

Ans. Refer Chapter 13, Section 13.8, Page No.13.7.

(ii) Explain the working principle of any two types of pneumatic position sensing devices. *(6)*

Ans. Refer Chapter 15, Section 15.5, Page No.15.11.

15. ***(a) (i) Explain with block diagram the components present in a PLC and give their functions.*** *(8)*

Ans. Refer Chapter 15, Section 15.9, Page No.15.21.

(ii) What is cascade control? Explain giving suitable example circuit. *(8)*

Ans. Refer Chapter 13, Section 13.26.1, Page No.13.28.

[OR]

(b) (i) Briefly explain the maintenance requirements for hydraulic power packs. *(6)*

Ans. Refer Chapter 16, Section 16.2.4, Page No.16.3.

(ii) Explain the lay out of pneumatic systems with emphasis on sizing of conductors, cleanliness, traps and pressure regulation. *(6)*

Ans. Refer Chapter 10, Section 10.4, Page No.10.5.

(iii) Explain the principle of low cost automation. *(4)*

Ans. This question is beyond the scope of the 2004 regulation syllabus.

□□

B.E./B.Tech. Degree Examination, November/December 2006

Fifth Semester – Mechanical Engineering (Regulation 2004)

ME 1305 – APPLIED HYDRAULICS AND PNEUMATICS

Time : Three hours **Maximum : 100 marks**

Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. ***Define fluid power.***

Ans. Refer Q.No.1, A.U., Nov/Dec 2005.

2. ***Explain the term friction factor.***

Friction factor is a dimensionless number required to calculate the energy losses due to friction in the pipe. For laminar flow, the friction factor '*f*' is function of Reynolds number only whereas for turbulent flow '*f*' is a function of Reynolds number as well as the relative roughness of the pipe.

3. ***What do you mean by non-positive displacement pump? State its implications.***

In non-positive displacement pumps, the fluid flow is achieved using the inertia of the fluid in motion. Since these pumps cannot withstand high pressures, they are used only for transporting from one place to another. For the same reason, they are not preferred in the fluid power industries.

4. ***What is cylinder cushion? What is its purpose?***
When the pressurized fluid is allowed to enter inside the cylinder, the piston accelerates and travels in the cylinder barrel. If the piston is allowed to travel at the same speed till the end of the stroke, it will hit the end cap with a great impact. To avoid this impact, the piston needs to decelerate at the end of the travel. The arrangement made at the end caps to achieve the same is called 'cylinder cushion'.

5. ***Differentiate between pressure control valve and pressure relief valve.***
Pressure control valve controls the fluid pressure in a system whereas pressure relief valve protects a system from excessive fluid pressure over and above the design pressure limit.

6. ***Write the functions of a solenoid valve.***
A solenoid is an electromagnetic mechanical transducer that converts an electrical signal into a mechanical output force. It provides a push or pull force to remotely operate fluid power valves.

7. ***What is the need of lubricator unit in the pneumatic system?***
The function of the lubricator unit is to add a controlled amount of oil with air to ensure proper lubrication of internal moving parts of pneumatic components.

8. ***Name the various types of filters used in the pneumatic system.***
   1. Dry filters (with replaceable cartridges), and
   2. Wet filters (where the incoming air is bubbled through an oil bath then passed through a wire mesh filter).

9. ***What is servo valve? How does it work?***
   - ✓ Servo valves are nothing but DC valves having infinitely variable positioning capability.
   - ✓ A servo system is one in which the comparatively large amount of power is controlled by small impulses or command signals and any errors are corrected by feedback signals.

10. ***Define Coanda effect.***
"When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."

Part B – (5 × 16 = 80 marks)

11. *(a) (i) With neat sketch explain the hydraulic and pneumatic fluid power systems.* (12)
Ans. Refer Chapter 1, Sections 1.7 & 1.8, Page Nos. 1.9 & 1.12.
(ii) Discuss the properties of the hydraulic fluids. (4)
Ans. Refer Chapter 2, Section 2.3, Page No.2.4.

[OR]

(b) How to calculate frictional losses in common valves and fittings. (8)
Ans. Refer Chapter 4, Section 4.15, Page No.4.17.
(ii) Define Reynolds number. (2)
Ans. Refer Chapter 4, Section 4.7, Page No.4.10.

(iii) Differentiate between laminar and turbulent fluid flow. (6)
Ans. Refer Chapter 4, Section 4.6, Page No.4.9.

12. *(a) (i) Explain the working principle of external gear pump and determine its performance measures.* (12)
Ans. Refer Chapter 5, Section 5.5, Page No.5.6.
(ii) Write short notes on variable displacement pumps. (4)
Ans. Refer Chapter 5, Section 5.3.1, Page No.5.4.

[OR]

(b) Explain the various mechanisms of hydraulic cylinder mountings with neat diagram. (16)
Ans. Refer Appendix I, Article 5, Page No.A.4.

13. *(a) (i) Explain the operational features of the check valve with neat diagram.* (10)
Ans. Refer Chapter 7, Section 7.7, Page No.7.5.
(ii) Write short notes on shuttle valve. (6)
Ans. Refer Chapter 7, Section 7.11, Page No.7.18.

[OR]

(b) (i) Explain air over oil intensifier system with suitable example. (10)
Ans. Refer Chapter 8, Section 8.14.2, Page No.8.27.
(ii) With neat sketch explain the weight loaded accumulator. (6)
Ans. Refer Chapter 8, Section 8.3, Page No.8.4.

14. *(a) What is compressor? Explain the working principle of piston type compressor with neat sketch.* (16)
Ans. Refer Chapter 11, Section 11.3, Page No.11.2.

[OR]

(b) What is synchronizing? Explain the synchronizing circuit with suitable approaches. (16)
Ans. Refer Chapter 13, Section 13.10, Page No.13.10.

15. *(a) Explain the hydro mechanical servo system with suitable application.* (16)
Ans. Refer Chapter 14, Section 14.4, Page No.14.3.

[OR]

(b) How PLC is used in fluid power control? Explain with a suitable application. (16)
Ans. Refer Chapter 15, Section 15.8, Page No.15.20.

□□

B.E./B.Tech. Degree Examination, November/December 2006

Sixth Semester – Mechanical Engineering (Regulation 2004)

ME 1305 – HYDRAULIC AND PNEUMATIC CONTROLS

Time : Three hours **Maximum : 100 marks**

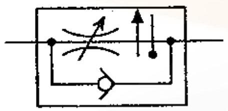
Answer ALL questions.

Part A – (10 × 2 = 20 marks)

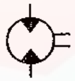
1. ***Differentiate pressure compensated and non-pressure compensated pumps.***

In pressure compensated pump, the pump flow can be made to zero. Such a pump has its own protection against excessive pressure build up. Also there is no power waste and reduced fluid heading. Whereas non-pressure compensated pumps are hydraulically unbalanced and cause undesirable side load on the bearings of the pump.

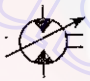
2. ***Draw the hydraulic symbols for a pressure-temperature compensated flow control valve and bidirectional motor.***



Pressure temperature compensated flow control valve



Fixed displacement bidirectional motor



Variable displacement bidirectional motor

3. ***What is "meter-out" circuit? What are its limitations?***

✓ In 'meter-out' circuit, the flow control valve is placed in the return line limiting the flow rate of oil from the cylinder.

✓ ***Limitation:*** Even at no-load, the actuator is subjected to maximum pressure. Also, as the cylinder is fed with the entire pump pressure, pressure there is possibility of higher friction loss.

4. ***Define 'pressure override' in pressure control valves.***

The pressure at which the valve that opens is called the cracking pressure. The cracking and closing pressure of the control valve is not same. Moreover in most cases, the valve poppet cracks at a pressure lower than the adjusted pressure but the valve closes at a lower pressure than at which it cracks. This phenomenon is known as pressure override.

5. ***Highlight the need of using an accumulator in hydraulic circuits.***

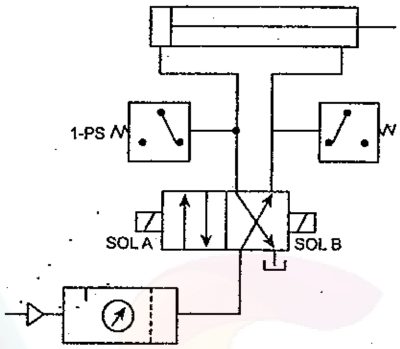
In hydraulic circuits, accumulators are used as:

(*i*) Leakage compensator,
(*ii*) Auxiliary power source,
(*iii*) Emergency power source,
(*iv*) Hydraulic shock absorber,
(*v*) Fluid make-up device,
(*vi*) Holding device, and
(*vii*) Lubricant dispenser.

6. ***State the role of PLC in fluid power industry.***

PLCs are designed as a replacement for hard-wired electro-mechanical relays to control fluid power systems.

7. ***Draw a circuit to automatically reciprocate a pneumatic cylinder using a pressure switch.***



8. ***What is twin pressure valve?***

Twin pressure valve, like counter balance valve, permits free flow in one direction and restricted flow in the opposite direction.

9. ***How do you rate a compressor?***

Air compressors are generally rated by the following:

(*i*) Outlet pressure of air that can be delivered by the compressor,
(*ii*) Capacity or volume of air that can be delivered by the compressor, and
(*iii*) Compressor configuration and cylinder geometry.

10. ***What are the important components of a hydraulic power pack?***

Hydraulic power pack consists of the pump, drive motor, mechanical couplings, oil reservoir, strainers, filters, coolers, *etc.*

Part B – (5 × 16 = 80 marks)

11. *(a) (i) What are the advantages of oil hydraulic systems over other methods?* (4)

Ans. Refer Chapter 1, Section 1.4.1, Page No.1.5.

(ii) A gear pump has a displacement of 60,000 m³. It delivers 100 liters per minute at 1440 rpm and 8 N/mm². If the prime mover input torque is 75 N.m.,

(1) Find overall efficiency of the pump. (4)

(2) The theoretical torque required to operate the pump. (8)

Also derive the equations for the volumetric discharge, efficiency and torque.

Ans. The solution to this problem is very much similar to the Example 5.7 in our text. Only numerical values have been changed. So proceed in the similar fashion as that of Example 5.7, Chapter 5, Page No.5.34.

[OR]

(b) With a neat sketch explain the principle, construction, working, advantages, limitations and applications of a non-pressure compensated reciprocating vane pump.

Ans. Refer Chapter 5, Section 5.10, Page No.5.14. (16)

12. *(a) (i) Explain with a circuit how in a shaping operation a fast approach, slow feed and rapid return can be achieved.* *(8)*

Ans. Refer Chapter 13, Section 13.6, Page No.13.6.

(ii) Explain with a circuit the technique of how a punching operation can be achieved. *(8)*

Ans. Refer Chapter 8, Section 8.14, Page No.8.26.

[OR]

(b) Explain with suitable circuits how the following requirements can be achieved in an industry.

(i) Safety of the operator by using two handed push buttons. *(8)*

(ii) The system can be protected from high pressures. *(8)*

Ans. (*i*) Refer Chapter 13, Section 13.13, Page No.13.19.

(*ii*) Refer A.U., April/May 2005, Q.No.13(*a*)(*ii*), Page No.S.4.

13. *(a) Design a punching press with five working stations operated by five single acting cylinders connected to an intensifier. The cylinders require 20 mm travel and used to punch 20mm diameter holes on sheet metals of 5 mm thick of mild steel whose strength is 360 MPa. Determine the oil pressure of the hydraulic system and length of the intensifying cylinder if the load piston area is 20000 mm^2, ram piston area and small piston area of the intensifier are 15000 mm^2 and 900 mm^2.* *(16)*

[OR]

(b) Design a car crushing system. The crushing force required is such that a 20 cm diameter cylinder is required at a working pressure of 130 kg/cm^2. Time for crushing is about 10 sec and the stroke required to flatten the car is 300 cm. Compare the power requirements of a circuit without and with accumulator.

Accumulator details: It is a gas loaded accumulator.

Time taken for charging = 6 min

Initial pressure of charging (precharged), P_1 = 100 kg/cm^2

Charged pressure of accumulator, P_2 = 225 kg/cm^2

Minimum pressure for crushing, P_3 = 130 kg/cm^2 *(16)*

Ans. The solution to this problem is very much similar to Example 8.6 in our text. Only numerical values have been changed. So proceed the solution as discussed in Example 8.6, Page No.8.21.

14. *(a) (i) Describe the operation of an "FRL" trio unit.* *(8)*

Ans. Refer Chapter 11, Section 11.9.5, Page No.11.15.

(ii) Explain with ANSI symbols.

(1) All the types of actuators used in pneumatics.

(2) Quick exhaust valve and silencer. *(8)*

Ans. (1) Refer Chapter 12, Section 12.9, Page No.12.9.

(2) Refer Chapters 12 & 11, Sections 12.7 & 11.10, Page Nos.12.7 & 11.16.

[OR]

(b) (i) Highlight the advantages of a air over oil circuit and explain it with a suitable application. ***(8)***

Ans. Refer Chapter 13, Section 13.23, Page No.13.26.

(ii) Brief on a electro hydraulic servo system used in industries. ***(8)***

Ans. Refer Chapter 14, Section 14.5.8, Page No.14.10.

15. ***(a) Three pneumatic cylinders A, B, C are used in an automatic sequence of operation. A cylinder extends, B cylinder retracts, C cylinder retracts and then A cylinder retracts, C cylinder extends and B cylinder extends. Develop pneumatic circuits by cascade method. Sketch also travel-step diagram and explain briefly.*** ***(15)***

Ans. For the given data, the operation sequence is $A^+ B^- C^- A^- C^+ B^+$. The pneumatic circuit for the sequence $A^+ B^- C^- A^- C^+ B^+$ using cascade method can be developed in the similar manner as presented in Example 13.6, Page No.13.34.

[OR]

(b) (i) Brief on the methodology adopted to install and maintain a pneumatic power pack. ***(10)***

Ans. Refer Chapter 16, Section 16.3.2, Page No.16.11.

(ii) Write short notes on low cost automation. ***(6)***

Ans. Low cost automation is defined as a technology that creates some degree of automation around the existing equipment, tools and methods, using mostly the standard equipments and softwares available in the market.

□□□

Apprise Education, Reprise Innovations

B.E./B.Tech. Degree Examination, November/December 2007

Fifth Semester – Mechanical Engineering
(Regulation 2004)

ME 1305 – APPLIED HYDRAULICS AND PNEUMATICS

Time: Three hours **Maximum: 100 marks**

Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. ***State four advantages of fluid power.***

(*i*) Ease and accuracy of control.

(*ii*) Multiplication of force.

(*iii*) Constant force or torque.

(*iv*) Simplicity, safety, and economy.

What is low cost automation?

Low cost automation is defined as a technology that creates some degree of automation around the existing equipment, tools and methods, using mostly the standard equipments and softwares available in the market.

What are the major components of a hydraulic system?

1. Reservoir (or tank)
2. Pump
3. Prime mover
4. Valves
5. Actuator
6. Fluid-transfer piping

4. ***What is a positive displacement pump?***

✓ The positive displacement pump discharges a fixed quantity of fluid into the hydraulic system per revolution of pump shaft rotation.

✓ Since the flow of fluid is guaranteed on every revolution of the shaft, this type of pump is named as 'positive' displacement pump.

What are the control functions of different valves in hydraulic systems?

*1. **Directional control values:*** To control the direction of flow by which the direction of actuator is controlled.

*2. **Pressure control values:*** To control the pressure of the fluid in the circuit by which the force exerted by actuator is controlled.

*3. **Flow control values:*** To control the flowrate of fluid in the circuit by which the speed of the actuator is controlled.

6. ***What is an intensifier?***

Intensifier, also known as pressure intensifier or pressure booster, is a device used to compress the liquid in a hydraulic system to a value above the pump discharge pressure. It is analogous to a step-up electrical transformer.

7. ***What are the reasons for pressure drop in pneumatic lines?***

The reasons include sudden change in volume, leakage exist in the circuit line, change in temperature, bends, and restrictions present in the pipe line.

8. ***How are the air compressors classified?***

1. Reciprocating types—Piston type and diaphragm type compressors.
2. Rotary types—Screw type, flow type and vane type compressors.

9. ***Define fluidics.***

Fluidics is the technology that utilizes fluid flow phenomena in components and circuits to perform a wide variety of control functions (such as sensing, memory, timing and interfacing).

10. ***What is a regenerative system in a pneumatic circuit?***

Regenerative circuit is used to speed up the extending speed of a double-acting cylinder in such a way that the pipelines to both ends of the cylinder are connected in parallel and that on the ports of four way valve is blocked.

Part B – (5 × 16 = 80 marks)

11. *(a) What are the desirable properties of hydraulic fluids? Discuss any eight of them in detail.* *(16)*

Ans. Refer Chapter 2, Sections 2.4 to 2.11, Page No.2.4.

[OR]

(b) (i) What is Reynolds number? *(2)*

Ans. Refer Chapter 4, Section 4.7, Page No.4.10.

(ii) How is Reynolds number determined? *(2)*

Ans. Refer Chapter 4, Section 4.7, Page No.4.10.

(iii) Draw fluid power symbols of any six different types of valves. *(12)*

Ans. Refer Chapter 3, Sections 3.4 to 3.7, Page No.3.4.

12. *(a) (i) Explain the construction and working of a gear pump.* *(8)*

Ans. Refer Chapter 5, Section 5.5, Page No.5.6.

(ii) How is the capacity of a variable displacement vane pump is adjusted? Explain with a diagram. *(8)*

Ans. Refer Chapter 5, Section 5.11, Page No.5.14.

[OR]

(b) (i) What is cylinder cushioning? Explain with a diagram. *(8)*

Ans. Refer Chapter 6, Section 6.5, Page No.6.6.

(ii) Explain with a diagram the working of a telescopic cylinder. *(8)*

Ans. Refer Chapter 6, Section 6.6, Page No.6.7.

13. *(a) (i) How does a pilot operated direction control valve function? Explain with a diagram.* *(8)*

Ans. Refer Chapter 7, Section 7.7.4, Page No.7.6.

(ii) Discuss with a diagram the working of a non-return valve. *(8)*

Ans. Refer Chapter 12, Section 12.3, Page No.12.2.

[OR]

(b) (i) Two hydraulic cylinders have to work in sequence. Design a suitable circuit. Draw the circuit. *(8)*

Ans. Refer Chapter 13, Section 13.8, Page No.13.7.

(ii) An hydraulic cylinder is used for an industrial application. It has been decided to use an accumulator as leakage compensator. Design a circuit to fulfill these requirements. *(8)*

Ans. Refer Chapter 8, Section 8.11.1, Page No.8.11.

14. ***(a) (i) Discuss the working principle of an air compressor.*** *(8)*

Ans. Refer Chapter 11, Section 11.3, Page No.11.2.

(ii) Discuss the functions of FRL unit. *(8)*

Ans. Refer Chapter 11, Section 11.9.5, Page No.11.15.

[OR]

(b) (i) Explain the working of a pneumatic speed control circuit. *(8)*

Ans. Refer Chapter 13, Section 13.20, Page No.13.22.

(ii) What is time delay circuit? Discuss with an example. *(8)*

Ans. Refer Chapter 9, Section 9.2.7, Page No.9.5.

15. ***(a) (i) What is the selection criteria for pneumatic components?*** *(4)*

Ans. Refer Q.No.15(*b*) (*i*), Solved Anna University Question Papers, April/May 2005.

(ii) What are the factors considered during the installation of pneumatic systems? *(6)*

The various factors to be considered during the installation of pneumatic systems are given below:

1. ***Installation of FRL unit***—installed upstream from the other components.
2. ***Installation of cylinder***—properly mounted and perfectly aligned, it should be ensured that the cylinders are properly lubricated.
3. ***Installation of pipelines***—adequate filter between the main and the circuit to be ensured, water trap is to be fitted at the end of each branch line, piping should be sloped away from the compressor.
4. ***Installation of compressor***—compressor intake should be from the outside air, open end of intake pipeline screened to prevent rain and dirt entering.

(iii) What are the advantages of using fluidic systems? *(6)*

Ans. Refer Chapter 15, Section 15.2.2, Page No.15.2.

[OR]

(b) (i) What is Coanda effect? Explain with a diagram. *(4)*

Ans. Refer Chapter 15, Section 15.3.1, Page No.15.3.

(ii) Design a circuit with air pilot control of a double-acting cylinder. *(6)*

Ans. Refer Chapter 15, Section 15.6.1, Page No.15.15.

(iii) Explain with a circuit diagram how is the control of an air motor is achieved. A flow control valve is used to adjust the speed of the motor. *(6)*

Ans. Refer Chapter 13, Section 13.21, Page No.13.25.

❑❑❑

B.E./B.Tech. Degree Examination, April/May 2008

Fifth Semester – Mechanical Engineering

(Regulation 2004)

ME 1305 – APPLIED HYDRAULICS AND PNEUMATICS

Time: Three hours **Maximum: 100 marks**

Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. ***List any four advantages of using the fluid power system.***

(*i*) Ease and accuracy of control.

(*ii*) Multiplication of force.

(*iii*) Constant force or torque.

(*iv*) Simplicity, safety, and economy.

2. ***What is Viscosity Index? What do you infer from V.I. number of an oil?***

✓ The viscosity index (V.I) of a liquid is a number indicating the effect of a change in temperature on viscosity.

✓ The rate of change in viscosity with changes in temperature is relatively less with high V.I. oils than the low V.I. oils.

3. ***Name any four hydraulic fluids that are commonly used.***

1. Petroleum oils.
2. Water-in-oil and oil-in-water emulsions.
3. Glycols.
4. Phosphate esters.

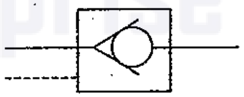
4. ***What is pump cavitation? How can you avoid it?***

✓ The formation, growth, and collapse of vapour filled cavities or bubbles in a flowing liquid due to local fall in fluid pressure is called pump cavitation.

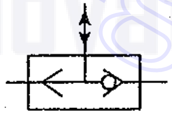
✓ Pump cavitation can be avoided by ensuring that the suction pressure is always greater than that required by the pump.

5. ***Draw the ANSI symbol for (a) Pilot operated check valve, (b) Shuttle valve.***

(*a*)



(*b*)



6. ***What is the use of a temperature switch?***

A temperature switch is an instrument that automatically senses a change in temperature and opens or closes an electrical switching element when a predetermined temperature point is reached.

7. ***How can you specify an air compressor?***

Air compressors are generally specified by the following :

(*i*) Outlet pressure of air that can be delivered by the compressor,

(*ii*) Capacity of volume of air that can be delivered by the compressor, and

(*iii*) Compressor configuration and cylinder geometry.

8. ***What is meant by an air-over-oil system?***

The air-over-oil system was both air and oil to obtain the advantages of each medium. By the use of these two media, the quick action of air and the smooth high-pressure action of oil can be blended.

9. ***Define the terms 'Lap' and 'Null' with respect to servo valves.***

✓ ***Lap*** is the length relationship between the metering lands to the spool and the port openings in the sleeve or body.

✓ ***Null*** is the relational condition between the spool and valve port where the valve supplies no control flow at zero load pressure drop.

10. ***State 'Coanda effect'.***

"When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."

Part B – (5 × 16 = 80 marks)

11. *(a) (i) List out the advantages and disadvantages of hydraulic power system.* *(8)*

Ans. Refer Chapter 1, Section 1.4, Page No.1.4.

(ii) What are the functions of a fluid in any fluid power systems? *(4)*

Ans. Refer Chapter 2, Section 2.1.1, Page No.2.1.

(iii) What are the required properties of a good hydraulic fluid? *(4)*

Ans. Refer Chapter 2, Section 2.4, Page No.2.4.

[OR]

(b) Write short notes on the following:

(i) Laminar and turbulent flow. *(8)*

(ii) Energy losses in valves and fittings. *(3)*

(iii) Darcy's equation. *(5)*

Ans. (*i*) Refer Chapter 4, Section 4.6, Page No.4.9.

(*ii*) Refer Chapter 4, Section 4.13, Page No.4.13.

(*iii*) Refer Chapter 4, Section 4.14, Page No.4.14.

12. *(a) (i) How much hydraulic power would a pump produce when operating at 125 bars and delivering 1.25 litres per second of oil? What power rated electric motor would be selected to drive this pump if its overall efficiency is 88%.* *(8)*

Ans. Refer Chapter 5, Example 5.9, Page No.5.35.

(ii) What are the factors to be considered in selection of a pump? *(8)*

Ans. Refer Chapter 5, Example 5.9, Page No.5.35.

[OR]

(b) (i) Explain with neat sketch, the principle and operation of telescopic cylinder.(10)

Ans. Refer Chapter 6, Section 6.6, Page No.6.7.

(ii) With respect to hydraulic motors, define the following terms: *(6)*

(1) Volumetric efficiency.

(2) Mechanical efficiency.

(3) Overall efficiency.

Ans. Refer Chapter 6, Section 6.14, Page No.6.17.

13. *(a) (i) Explain the sequencing of two double-acting cylinders with a neat circuit.* *(8)*

Ans. Refer Chapter 13, Section 13.8, Page No.13.7.

(ii) With a neat sketch describe the construction and operation of a pressure compensated flow control valve. *(8)*

Ans. Refer Chapter 7, Section 7.22, Page No.7.26.

[OR]

(b) (i) With a neat sketch, explain how two hydraulic cylinders motion can be synchronized. *(8)*

Ans. Refer Chapter 13, Section 13.10, Page No.13.10.

(ii) Make a circuit, showing an intensifier in a punching press application. *(8)*

Ans. Refer Chapter 8, Section 8.14, Page No.8.26.

14. *(a) (i) A rotary vane air motor has a displacement volume of 80 cm^3 and operates at 1750 rpm using 700 kW gauge pressure air. Calculate the standard m^3/min rate of consumption and kW power output of the motor. Assume the temperature remains constant.* *(10)*

(ii) Explain the function of an air pressure regulator with neat sketch. *(6)*

Ans. Refer Chapter 11, Section 11.8, Page No.11.12.

[OR]

(b) Develop an electropneumatic circuit by cascade method for the following sequence: $A^+B^+B^-A^-$ where A and B stand for cylinders, (+) indicates extension and (–) retraction of cylinders. *(16)*

Ans. Refer Chapter 13, Example 13.3, Page No.13.32.

15. *(a) (i) Draw and explain the working of proportional pressure reducing valve.* *(8)*

Ans. Refer Chapter 7, Section 7.16, Page No.7.22.

(ii) What is meant by ladder programming? *(3)*

Ans. Refer Chapter 15, Section 15.10.1, Page No.15.22.

(iii) Draw the basic standard symbols that are used in ladder diagram? Also show rungs in a ladder diagram. *(5)*

Ans. Refer Chapter 9, Section 9.3, Page No.9.6.

[OR]

(b) (i) Describe various selection criteria for pneumatic components. *(6)*

Ans. Refer Chapter 10, Section 10.2.6, Page No.10.2.

(ii) List out any four operating problems associated with pumps and valves and the corresponding possible causes and suitable remedy for each problem. *(10)*

Ans. Refer Chapter 16, Section 16.2.4, Page No.16.3.

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B.E./B.Tech. Degree Examination, November/December 2008

Fifth Semester – Mechanical Engineering

(Regulation 2004)

ME 1305 – APPLIED HYDRAULICS AND PNEUMATICS

Time: Three hours **Maximum: 100 marks**

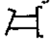
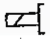
Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. *State the effect of temperature and pressure on viscosity of gases.*

   The viscosity of gases increase with increase in temperature. Over the normal range of pressures, the viscosity of gases is found to be independent of pressure.

2. *For the following graphical symbols shown, identify their modes of operation.*

   (a)  *(b)* 

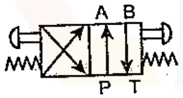
   (*a*) Pedal actuation,

   (*b*) Solenoid actuation.

3. *How do you specify a pump?*

   A pump can be specified by its capacity, discharge pressure, and speed of rotation.

4. *Draw the graphical symbol for: push button operated, four way, two position, spring offset DCV.*



5. *What are the functions of accumulators?*

   ✓ An accumulator is a pressure storage reservoir in which a non-compressible hydraulic fluid is retained under pressure from an external source.

   ✓ The function of hydraulic accumulator is analogous to that of a capacitor in an electrical circuit.

6. *What is the purpose of an air pressure regulator?*

   The function of the air pressure regulator is to regulate the pressure of the incoming compressed air so as to achieve the desired air pressure at a steady condition.

7. *What is the purpose of fail-safe circuit?*

   Fail safe circuit is designed to safeguard the operator, the machine, and the workpiece. It prevents any possible injury to the operator or damage to the machine and the workpiece.

8. *What is bistable flip-slop?*

   The zero lap servo valve means that the edges of the spool lands are precisely made to line up with the metering ports in the valve sleeve.

9. *What are servo valves? Write their purpose in fluid power systems?*

   ✓ Servo valves are nothing but DC valves having infinitely variable positioning capability.

   ✓ The servo valves are used to control not only the direction of fluid flow, but also the amount of flow.

10. *State 'Coanda effect'.*

    "When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."

Part B – (5 × 16 = 80 marks)

11. *(a) (i) Compare and contrast hydraulic, pneumatic and electromechanical power systems.* *(10)*

    Ans. Refer Chapter 1, Section 1.9, Page No.1.15.

    (ii) Write briefly about the following hydraulic fluids. *(6)*

    (1) Petroleum oils

    (2) Emulsions

    (3) Glycols

    Ans. Refer Chapter 2, Section 2.24, Page No.2.14.

    [OR]

    (b) (i) List all properties that a good hydraulic fluid should possess. *(6)*

    Ans. Refer Chapter 2, Section 2.23, Page No.2.12.

    (ii) Fluid is flowing through a tapering pipe having diameters 50 mm and 25 mm at sections 1 and 2 respectively. The discharge through the pipe is 7.5 Lps (litres per second). The section 1 is 3 m above datum and section 2 is 1.25 m above datum. If the pressure at section 1 is 200 kPa, find the pressure at section 2. The specific gravity of the fluid is 0.9. *(10)*

    Ans. Refer Chapter 4, Section 4.10, Page No.4.21.

12. *(a) Explain the following:* *(16)*

    (i) Pump characteristic curves

    Ans. Refer Chapter 5, Section 5.17, Page No.5.26.

    (ii) Pump cavitation

    Ans. Refer Chapter 5, Section 5.18.3, Page No.5.31.

    (iii) Pump noise

    Ans. Refer Chapter 5, Section 5.18.1, Page No.5.30.

    (iv) Pump selection

    Ans. Refer Chapter 5, Section 5.19, Page No.5.31.

    [OR]

(b) (i) With a neat sketch, explain the 'end cushion' provided in hydraulic cylinder. (8)

Ans. Refer Chapter 6, Section 6.5, Page No.6.6.

(ii) Explain with neat sketch, the principle of operation of telescopic cylinder. (8)

Ans. Refer Chapter 6, Section 6.6, Page No.6.7.

13. *(a) (i) Explain the construction and working of pilot operated sequence valve.* (8)

Ans. Refer Chapter 7, Section 7.19.2, Page No.7.24.

(ii) Make a circuit sketch, showing the use of an accumulator, as a hydraulic shock absorber. (8)

Ans. Refer Chapter 8, Section 8.11.4, Page No.8.15.

[OR]

(b) (i) Draw and explain the ladder diagram connections for a regenerative circuit. (10)

Ans. Refer Chapter 9, Section 9.8, Page No.9.11.

(ii) Write and explain the working principle of pressure intensifier, with neat diagram. (6)

Ans. Refer Chapter 8, Section 8.13.2, Page No.8.23.

14. *(a) (i) Determine the actual power required to drive a compressor that delivers air at 3.5 standard m^3/min at 8 bar gauge. The overall efficiency of the compressor is 74%.* (8)

Ans. Refer Chapter 11, Example 11.3, Page No.11.9.

(ii) Make a circuit sketch for control of a double-acting hydraulic cylinder. (8)

Ans. Refer Chapter 13, Section 13.4, Page No.13.3.

[OR]

(b) Design an electropneumatic circuit using cascade method for the following sequence $A^+B^+B^-A^-$ where A and B stands for cylinders, (+) indicates extension and (–) indicates retraction of cylinders. (16)

Ans. Refer Chapter 13, Example 13.3, Page No.13.32.

15. *(a) (i) Explain the construction and working principle of hydromechanical servovalves with neat diagram.* (12)

Ans. Refer Chapter 14, Section 14.3, Page No.14.2.

(ii) What are proportional control valves? Write the types of proportional control valves? (4)

Ans. Refer Chapter 14, Section 14.6, Page No.14.11.

[OR]

(b) (i) Describe various selection criteria for pneumatic components. (6)

Ans. Refer Chapter 10, Section 10.2.6, Page No.10.2.

(ii) Explain the working principle of a PLC with neat block diagram. (10)

Ans. Refer Chapter 15, Section 15.8, Page No.15.20.

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B.E./B.Tech. Degree Examination, May/June 2009

Fifth Semester – Mechanical Engineering (Regulation 2004)

ME 1305 – APPLIED HYDRAULICS AND PNEUMATICS

Time: Three hours **Maximum: 100 marks**

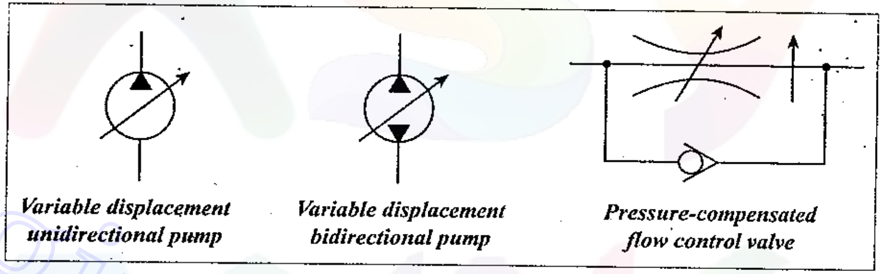
Answer ALL questions.

Part A – (10 × 2 = 20 marks)

1. *List out any four desirable properties of hydraulic fluids.*

   (*i*) Stable viscosity charactristics,
   (*ii*) Good lubricity,
   (*iii*) Compability with system materials, and
   (*iv*) Good heat dissipation capability.

2. *Give the symbol of variable vane pump and pressure compensated flow control valve.*



Variable displacement unidirectional pump

Variable displacement bidirectional pump

Pressure-compensated flow control valve

3. *A positive displacement pump has an overall efficiency of 87% and volumetric efficiency of 93%, what is its mechanical efficiency?*

☺ ***Solution:*** $\eta_{\text{overall}} = \eta_{\text{mech}} \times \eta_{\text{vol}}$

$$\therefore \quad \eta_{\text{mech}} = \frac{\eta_{\text{overll}}}{\eta_{\text{vol}}} = \frac{0.87}{0.93} \times 100 = 93.548\% \quad \textbf{Ans.}$$

4. *What are the advantages of telescope cylinders?*

   ✓ Telescopic cylinders are used where there is a space constraint.

   ✓ Such cylinders are useful for applications requiring a long stroke but with only limited space available for the unextended ram.

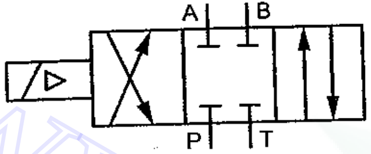
5. *What is the function of a sequence valve?*

   The sequence valve is used to control the fluid flow to ensure several operations in a particular order of priority in the system.

6. *Why weight loaded type accumulator is undesirable for mobile equipment?*

   Because of the weight loaded type accumulator is very heavy; not portable; and do not respond quickly to changes in the system demand.

7. *Give the symbol for an electro-pneumatic 3 position 4 way DC valve.*



8. ***Why a lubricator should be used in pneumatic system.***
The air lubricator is used to add a controlled amount of oil with air to ensure proper lubrication of internal moving parts of pneumatic components.

9. ***Where can fluidics be applied?***
Fluidic control systems are applied to perform a wide variety of control functions with the requirements of exceptional thermal and physical stability and ruggedness, insensitiveness to radiation, very minimal vibration and shock. *etc.,*

10. ***List the components present in PLC.***
1. Central processing unit (CPU),
2. Programmer/monitor (PM), and
3. Input/Output module (I/O).

Part B – (5 × 16 = 80 marks)

11. ***(a) (i) Describe any four advantages of fluid power systems.*** **(8)**
Ans. Refer Chapter 1, Section 1.4, Page No.1.4.
(ii) Differentiate between laminar and turbulent flow with examples. **(8)**
Ans. Refer Chapter 4, Section 4.6, Page No.4.9.

[OR]

(b) (i) Describe any four applications of fluid power systems. **(8)**
Ans. Refer Chapter 1, Section 1.5, Page No.1.8.
(ii) Draw a schematic layout of hydraulic power pack with symbols. **(8)**
Ans. Refer Chapters 1 & 3, Sections 1.7 & 3.2, Page Nos.1.9 & 3.9.

12. ***(a) Draw a neat sketch of an unbalanced type vane pump, explain its construction and operation and also show how the same can operate as a reversible pump. Also given its standard graphical symbol.*** **(16)**
Ans. Refer Chapter 5, Section 5.10, Page No.5.14.

[OR]

(b) (i) Describe the working of an external gear pump with a diagram. **(8)**
Ans. Refer Chapter 5, Section 5.5, Page No.5.6.
(ii) Explain briefly about the fluid motors. **(8)**
Ans. Refer Chapter 6, Section 6.9, Page No.6.10.

13. ***(a) (i) Sketch and explain commonly used 3-position 4-way direction control valves.(8)***
Ans. Refer Chapter 7, Section 7.10.2, Page No.7.15.

(ii) With the help of circuit diagrams, illustrate the application of accumulators. **(8)**
Ans. Refer Chapter 8, Section 8.11, Page No.8.11.

[OR]

(b) (i) Design and explain the working of a regenerative circuit. **(8)**
Ans. Refer Chapter 9 (or 13), Section 9.8 (or 13.5), Page No.9.11 (or 13.4).
(ii) Design and explain the working of a sequencing circuit. **(8)**
Ans. Refer Chapter 9 (or 13), Section 9.7 (or) 13.8), Page No.9.10 (or 13.7).

14. ***(a) (i) Draw and explain the functions of an air filter.*** **(8)**
Ans. Refer Chapter 11, Section 11.7, Page No.11.10.
(ii) Draw and explain the functions of pneumatic check valve. **(8)**
Ans. Refer Chapter 12, Section 12.3, Page No.12.2.

[OR]

(b) Design a pneumatic circuit for the following sequence using cascade method: $A+B+B-A-C+C-$ **(16)**
Ans. Refer Chapter 13, Example 13.2, Page No.13.30.

15. ***(a) Explain with a neat sketch construction and operation of an electro-hydraulic servo valve. Also, deduce the expression for its open loop gain.*** **(16)**
Ans. Refer Chapter 14, Section 14.5, Page No.14.6 .

[OR]

(b) (i) Explain the working of fluidic amplifiers. **(8)**
Ans. *Fluidic amplifiers are nothing but flips-flops. So refer Chapter 15, Section 15.4, Page No.15.4.*
(ii) Describe PLC applications in fluid power control. **(8)**
Ans. Refer Chapter 15, Section 15.8, Page No.15.20.

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Appendixes

Appendix I

1. Saybolt Visiometer Experiment
2. Comparison of Hydraulic Oils
3. Reynolds' Experiment
4. Working of a Centrifugal Pump
5. Mounting Arrangements for Linear Actuators
6. Applications of Linear Actuators
7. Laws of Boolean Algebra

Appendix II

A. Unit Conversion Factors

B. Greek Alphabets

C. Prefix Names of Multiples and Submultiples

D. Viscosity Conversion Scale and Nomogram

E. Pipe Sizing Chart

F. Fluid Power Symbols

APPENDIX – I

ARTICLE 1 : SAYBOLT VISCOMETER EXPERIMENT

Introduction

The instrument most oftenly used by engineers and technicians to measure the viscosity of liquids is the Saybolt viscometer or viscosimeter. This instrument measures the number of seconds it takes for a fixed quantity of liquid (60 cm^3) to flow through a small orifice of standard length and diameter at a specified temperature. The viscosity is measured as Seconds Saybolt Universal or Saybolt Universal Seconds (SSU/SUS) at certain temperature. For example, certain oil might have a viscosity of 80 SSU/SUS at 130°F.

Arrangement and Experiment

A typical arrangement of a Saybolt viscometer is depicted in Fig.A.1.

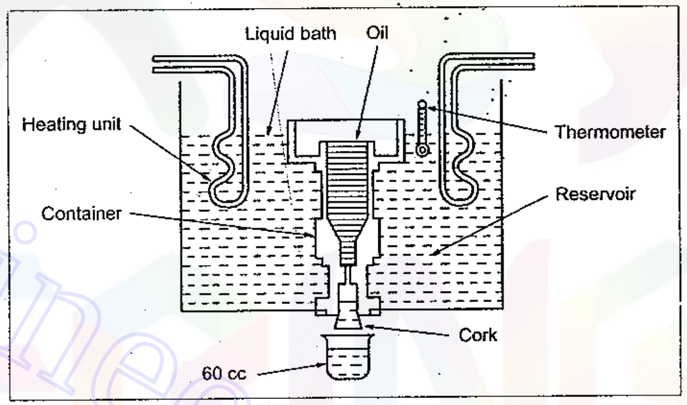

Fig. A.1. Saybolt viscometer

The Saybolt Universal viscometer consists of an oil chamber surrounded by a liquid bath heated by heating coils to bring the oil to the temperature at which the viscosity has to be measured. A standard orifice is located at the bottom of the center oil chamber. When the oil samples is at the desired temperature, the time taken (t sec) to fill a 60 cm^3 container through the metering orifice is then recorded and it is the viscosity of the oil in SSU/SUS. SSU/SUS viscosity will be higher for the thick fluid when compared to thin liquid.

ARTICLE 2 : COMPARISON OF HYDRAULIC OILS

Table A.1 presents the comparison of a few commonly used hydraulic oils.

Table A.1. Comparison of various hydraulic oils

Properties	Mineral oil	Water-oil emulsion	Water glycol	Phosphate ester	Chlorinated hydrocarbon
1. Specific gravity	0.864	0.916	1.060	1.275	1.43
2. Viscosity (at 100°F *i.e.*, 37.75°C)	100 – 200 SSU	145 SSU	200 SSU	200 SSU	145 SSU
3. Viscosity index (V.I. number)	70 – 100	—	150	40 – 50	30 – 40
4. Flash point (°C)	221°C	None	None	260°C	216°C
Maximum heating temperature (°C)	107°C	65°C	65°C	150°C	150°C
6. Lubricity	Very good	Fair	Fair	Very good	Good
7. Corrosion and rust prevention	Very good	Fair to good	Fair	Fair to good	Fair to good
Major drawback	Flammable	Shear breakdown	Poor lubricant	Seal compatibility problem	Seal compatibility problem
9. Common seal material	Synthetic rubber	Synthetic rubber	Synthetic rubber	Butyl silicon	Butyl and silicon
10. Suitability to roller bearing	Very good	Fair	Poor	Very good	Very good

ARTICLE 3 : REYNOLDS' EXPERIMENT

Osborne Reynolds in 1883 has demonstrated that two entirely different types of fluid flow—laminar and turbulent—exist.

Arrangement

The apparatus used by Reynolds was basically as shown in Fig.A.2.

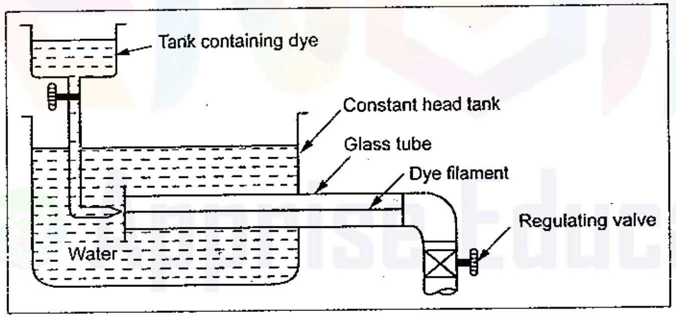

Fig. A.2. Reynolds apparatus

As shown in Fig.A.2, Reynolds' apparatus consists of the following four elements :

(*i*) A constant head tank filled with water,

(*ii*) A small tank containing dye (specific weight of dye same as that of water),

(*iii*) A horizontal glass tube provided with a bell mounted entrance, and

(*iv*) A regulating valve.

Procedure

The water was made to flow from the tank through the glass tube into the atmosphere and the velocity of flow was varied by adjusting valve. The liquid dye was introduced into the flow at the bell mouth through a small tube as shown in Fig.2. By observing the behaviour of the stream of dye, Reynolds was able to study the way in which the water was flowing along the glass tube.

Observations Made

1. When the velocity of flow was low, the dye remained in the form of a straight and stable filament passing through the glass tube so steadily that it scarcely seemed to be in motion. This was a case of ***laminar flow*** as shown in Fig.A.3(*a*).
2. With the increase of velocity a critical state was reached at which the dye filament showed irregularities and to waver as shown in Fig.A.3(*b*). This shows that the flow is no longer a laminar flow. This was a ***transitional state.***
3. With further increase in velocity of flow the fluctuations in the filament of dye became more intense and ultimately the dye diffused over the entire cross-section of the tube, due to the intermingling of the particles of the flowing fluid. This was the case of a ***turbulent flow*** as shown in Fig.A.3(*c*).

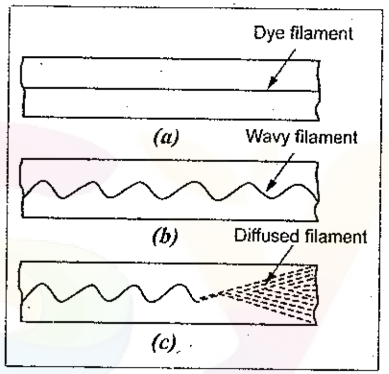

Fig.A.3. Appearance of dye filament in (a) laminar flow, (b) transition, and (c) turbulent flow

Reynolds Number

Reynolds from his experiment found that the nature of flow in a closed conduit depends upon the following factors :

(*i*) Diameter of the pipe (D), (*ii*) Density of the liquid (ρ),

(*iii*) Viscosity of the liquid (μ), and (*iv*) Velocity of flow (V).

By combining the above variable, Reynolds determined a non-dimensional quality equal to $\frac{\rho VD}{\mu}$ which is known as Reynolds number (Re).

$$\therefore \quad \text{Reynolds number, Re} = \frac{\rho VD}{\mu}$$

ARTICLE 4 : WORKING OF A CENTRIFUGAL (NON-POSITIVE DISPLACEMENT) PUMP

In non-positive displacement pumps, the fluid is displaced and transferred using the inertia of the fluid in motion. Some examples of non-positive displacement pumps are centrifugal pumps, propeller pumps, *etc.*

viscometer or viscosimeter. This instrument measures the number of seconds it takes for a fixed quantity of liquid (60 cm³) to flow through a small orifice of standard length and diameter at a specified temperature. The viscosity is measured as Seconds Saybolt Universal or Saybolt Universal Seconds (SSU/SUS) at certain temperature. For example, certain oil might have a viscosity of 80 SSU/SUS at 130°F.

Arrangement and Experiment

A typical arrangement of a Saybolt viscometer is depicted in Fig.A.1.

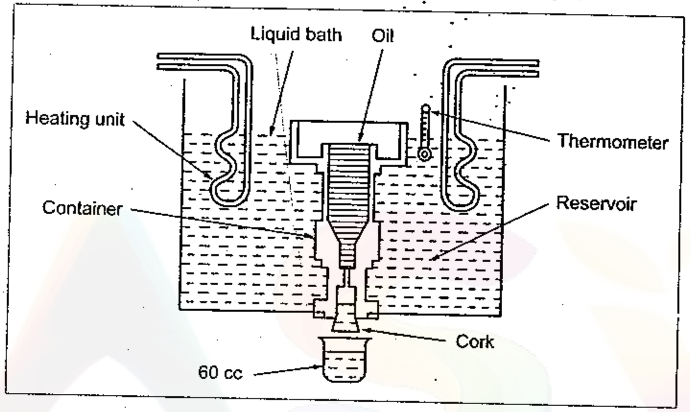

Fig. A.1. Saybolt viscometer

The Saybolt Universal viscometer consists of an oil chamber surrounded by a liquid bath heated by heating coils to bring the oil to the temperature at which the viscosity has to be measured. A standard orifice is located at the bottom of the center oil chamber. When the oil samples is at the desired temperature, the time taken (t sec) to fill a 60 cm³ container through the metering orifice is then recorded and it is the viscosity of the oil in SSU/SUS. SSU/SUS viscosity will be higher for the thick fluid when compared to thin liquid.

ARTICLE 2 : COMPARISON OF HYDRAULIC OILS

Table A.1 presents the comparison of a few commonly used hydraulic oils.

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multi-stage pump is equal to the head produced by stages.

ARTICLE 5 : MOUNTING ARRANGEMENTS FOR LINEAR ACTUATORS

One of the advantageous features of linear actuators (*i.e.*, hydraulic cylinders) is the variety of ways in which they can be mounted in a system. Several mounting arrangements for linear actuators are illustrated in Fig.A.5.

Fig. A.5. Mounting arrangements for linear actuators

ARTICLE 6 : APPLICATIONS OF LINEAR ACTUATORS

The nature of the force provided by a linear actuator depends on the kinematic linkage between the straight-line output of the cylinder and the point at which the force and motion are utilized. Because of the many alternatives in the design of the linkage, the linear actuator can be used to produce rotary or oscillatory motion as well as linear motion. The resultant ersatility of linear actuators is partially illustrated by the applications shown in Fig.A.6.

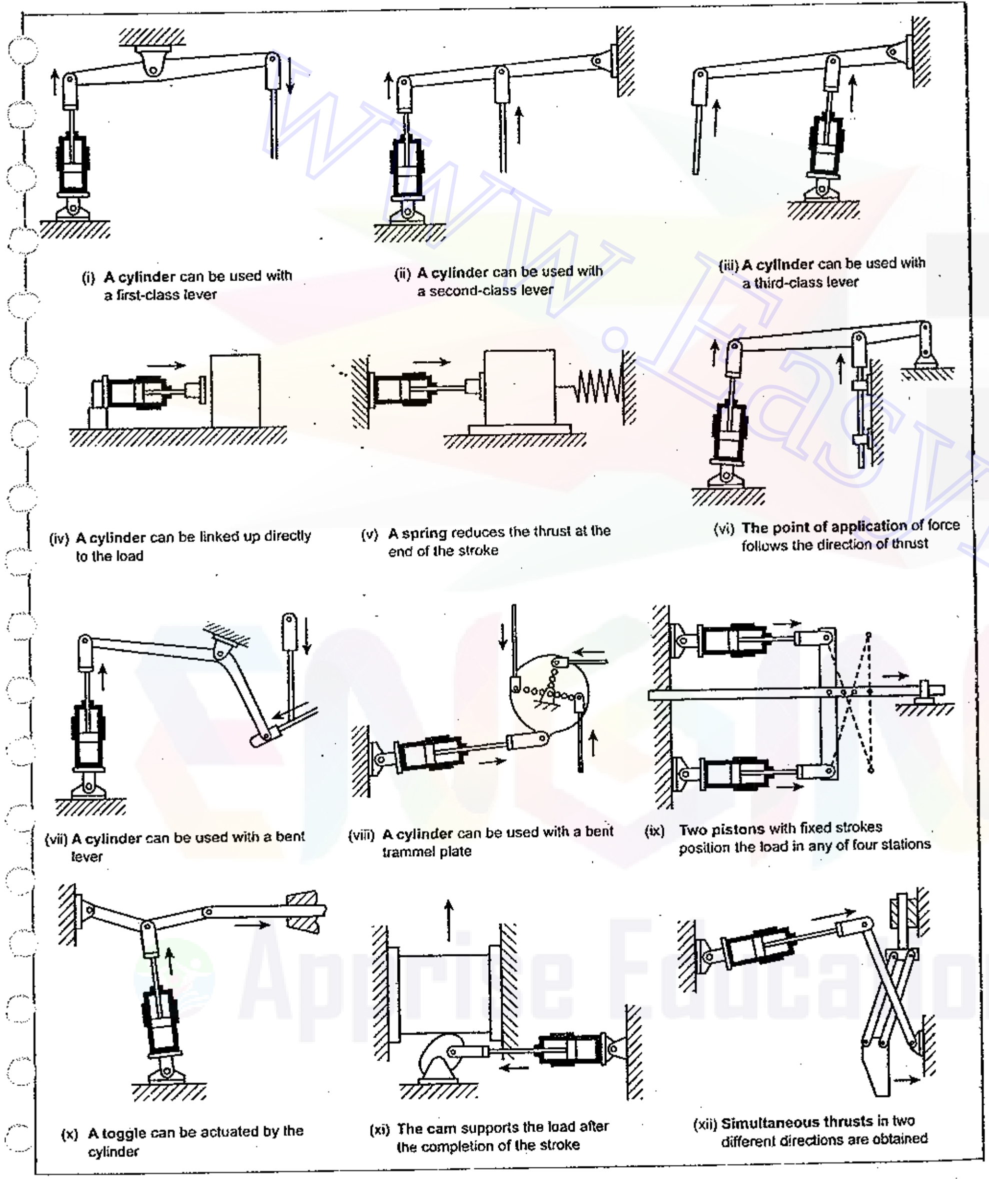

(i) A cylinder can be used with a first-class lever
(ii) A cylinder can be used with a second-class lever
(iii) A cylinder can be used with a third-class lever
(iv) A cylinder can be linked up directly to the load
(v) A spring reduces the thrust at the end of the stroke
(vi) The point of application of force follows the direction of thrust
(vii) A cylinder can be used with a bent lever
(viii) A cylinder can be used with a bent trammel plate
(ix) Two pistons with fixed strokes position the load in any of four stations
(x) A toggle can be actuated by the cylinder
(xi) The cam supports the load after the completion of the stroke
(xii) Simultaneous thrusts in two different directions are obtained

Fig. A.6. Applications of linear actuators (contd...)

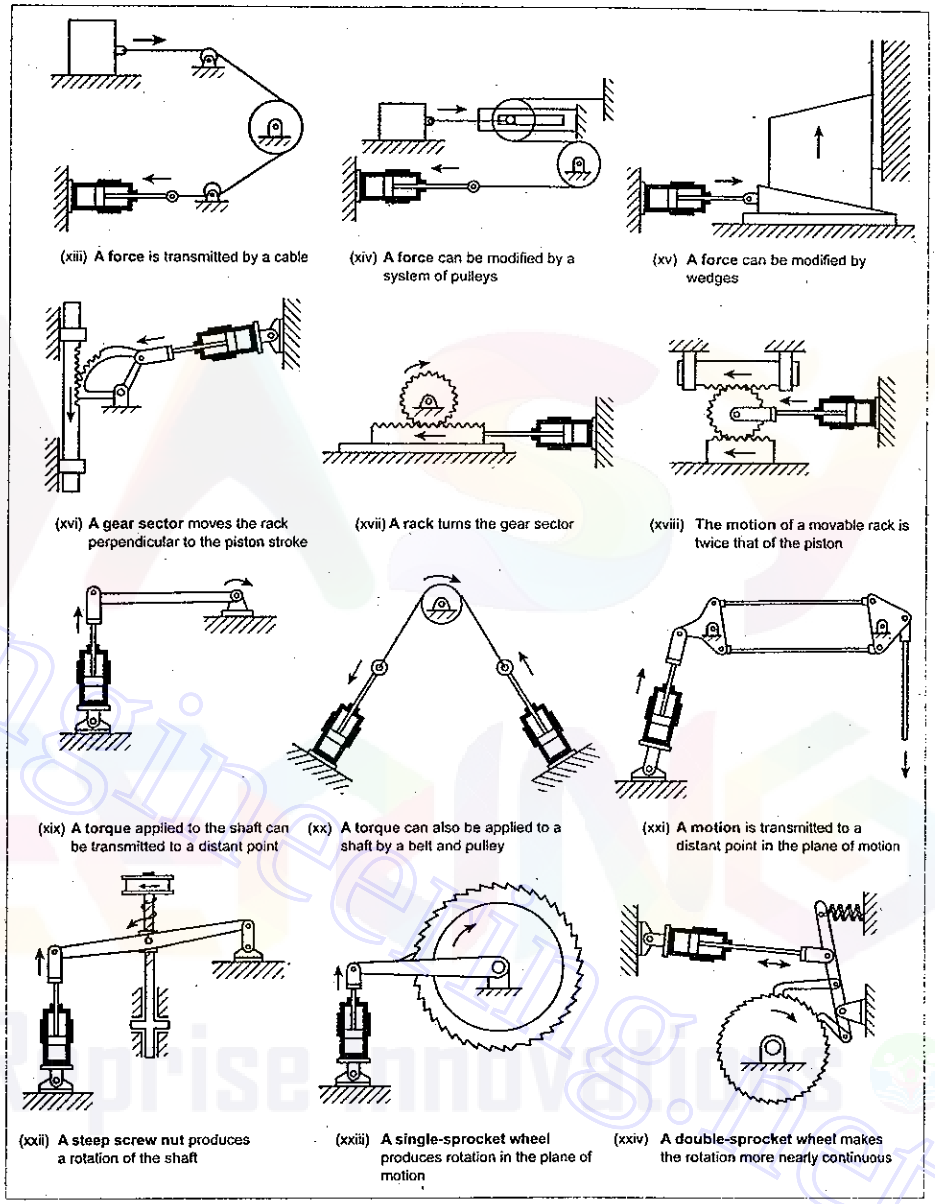

(xiii) A force is transmitted by a cable
(xiv) A force can be modified by a system of pulleys
(xv) A force can be modified by wedges
(xvi) A gear sector moves the rack perpendicular to the piston stroke
(xvii) A rack turns the gear sector
(xviii) The motion of a movable rack is twice that of the piston
(xix) A torque applied to the shaft can be transmitted to a distant point
(xx) A torque can also be applied to a shaft by a belt and pulley
(xxi) A motion is transmitted to a distant point in the plane of motion
(xxii) A steep screw nut produces a rotation of the shaft
(xxiii) A single-sprocket wheel produces rotation in the plane of motion
(xxiv) A double-sprocket wheel makes the rotation more nearly continuous

Fig. A.6. Applications of linear actuators

ARTICLE 7 : LAW OF BOOLEAN ALGEBRA

There are a number of laws of Boolean algebra that can be used in the analysis and design of fluid logic system. These laws are presented in Table A.2.

Table A.2. Laws of Boolean Algebra

Sum Form (OR)	Product Form (AND)
1. **Cummutative Law** $A + B = B + A$	$A \cdot B = B \cdot A$
2. **Associative Law** $A + B + C = (A + B) + C$ $= A + (B + C) \cdot$ $= (A + C) + B$	$A \cdot B \cdot C = (A \cdot B) \cdot C$ $= A \cdot (B \cdot C) = (A \cdot C) \cdot B$
3. **Distributive Law** $A + (B \cdot C) = (A + B) \cdot (A + C)$	$A \cdot (B + C) = (A \cdot B) + (A \cdot C)$
4. **Demorgan's Theorem** $\overline{A + B + C} = \bar{A} \cdot \bar{B} \cdot \bar{C}$	$\overline{A \cdot B \cdot C} = \bar{A} + \bar{B} + \bar{C}$
Additional Theorems	
5. $A + A = A$	$A \cdot A = A$
6. $A + 0 = A$	$A \cdot 0 = 0$
7. $A + 1 = 1$	$A \cdot 1 = A$
8. $A + (A \cdot B) = A$	$A \cdot (A + B) = A$
9. $A + \bar{A} = 1$	$A \cdot \bar{A} = 0$
10. $A \cdot \bar{B} + B = A + B$	$(A + \bar{B}) \cdot B = A \cdot B$
11. $A \cdot B + A \cdot B = A$	$(A + B) \cdot (A + \bar{B}) = A$

APPENDIX – II

A. UNIT CONVERSION FACTORS

Table A.3. Unit conversion factors

LENGTH

1 metre (m) = 3.281 foot (ft) = 1000 millimetre (mm) = 100 centimetre (cm)
1 inch (in) = 25.4 mm = 2.54 cm
1 yard (yd) = 0.9144 m

AREA

1 in^2 = 6.452 cm^2 ; 1 ft^2 = 0.0929 m^2

VOLUME

1 in^3 = 16.387 cm^3 ; 1 ft^3 = 28.317 litres (L)
1 gallon (gal) = 3.785 L = 231 in^3 = 0.135 ft^3 ; 1000 L = 1 m^3

MASS

1 kilogram (kg) = 2.2046 pound (lb) = 1000 gram (gm)
1 lb = 0.4536 kg ; 1 ton = 1016 kg ; 1 slug = 14.59 kg

FORCE

1 newton (N) = 0.2248 pound force (lbf) = 0.1019 kilogram force (kgf)
1 lbf = 4.448 N = 0.4534 kgf ; 1 kgf = 9.81 N = 2.205 lbf
1 N = 105 dynes (dyn) ; 1 N = 1 kg m s^{-2}

PRESSURE

1 bar = 105 pascal (Pa) = 14.5 pound force per square inch (psi) = 750 mm Hg
= 1.0197 $kgf.cm^{-2}$
1 atmosphere (atm) = 1.013 bar = 14.7 psi = 1.033 $kgf\text{-}cm^{-2}$
1 psi = 6895 Pa ; 1 Pa = 1 $N.m^{-2}$

VELOCITY

1 ft/s = 0.3048 m/s ; 1 rpm = 0.1047 rad/s

WORK (ENERGY)

1 joule (J) = 1 N.m = 1 $kg.m^2.s^{-2}$ = 10^7 ergs = 0.7376 ft.lbf
1 J = 2.788 × 10^{-7} kilowatt hour (kWh) = 0.2388 calories
= 9.487 × 10^{-4} British thermal units (Btu)

POWER

1 horse power (hp) = 745.7 W = 550 ft.lb/s = 42.4 Btu/min

FLOW RATE

1 ft^3/s = 0.0284 m^3/s = 448 grams per minute (gpm) ; 1 gpm
= 0.0632 litres per second (Lps)

VISCOSITY

Viscosity (absolute) : 1 $N.s/m^2$ = 10 poise ; 1 porse = 1 $dyn.s/cm^2$
1 $lb.s/ft^2$ = 47.88 Pa.s
Viscosity (kinematic) : 1 m^2/s = 10,000 strokes ; 1 stroke = 1 cm^2/s
1 ft^2/s = 0.0929 m^2/s

TEMPERATURE

T (°C) = (°F–32) × 0.556 ; T(K) = T(°C) + 273
T (°F) = (°C × 1.8) + 32

B. GREEK ALPHABETS

Table A.4. Greek alphabets

Name	Forms	Sound	Name	Forms	Sound
alpha	α	a	nu	ν	n
beta	β	b	xi	ξ, Ξ	x
gamma	γ, Γ	g	omicron	ο	o
delta	δ, Δ	d	pi	π, Π	p
epsilon	ε	e	rho	ρ	r
zeta	ζ	z	sigma	σ, Σ	s
eta	η	e	tau	τ	t
theta	θ, Θ	th	upsilon	υ	u
iota	ι	i	phi	ϕ, Φ	ph
kappa	κ	k	khi	χ	kh
lamda	λ, Λ	l	psi	φ, ψ	ps
mu	μ	m	omega	ω, Ω	o

C. PREFIX NAMES OF MULTIPLES AND SUBMULTIPLES

Table A.5. Prefix names of multiples and submultiples

Factor by which unit is multiplied	Name	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

D. VISCOSITY CONVERSION SCALE AND NOMOGRAM

Fig. A.7. Viscosity conversion scale from cSt to °E, SUS and RS

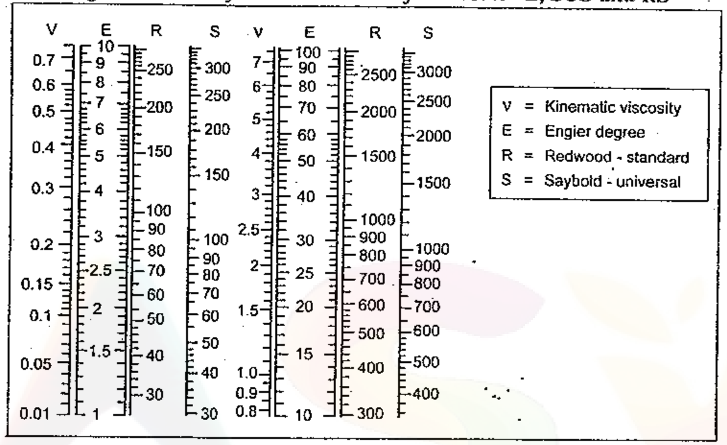
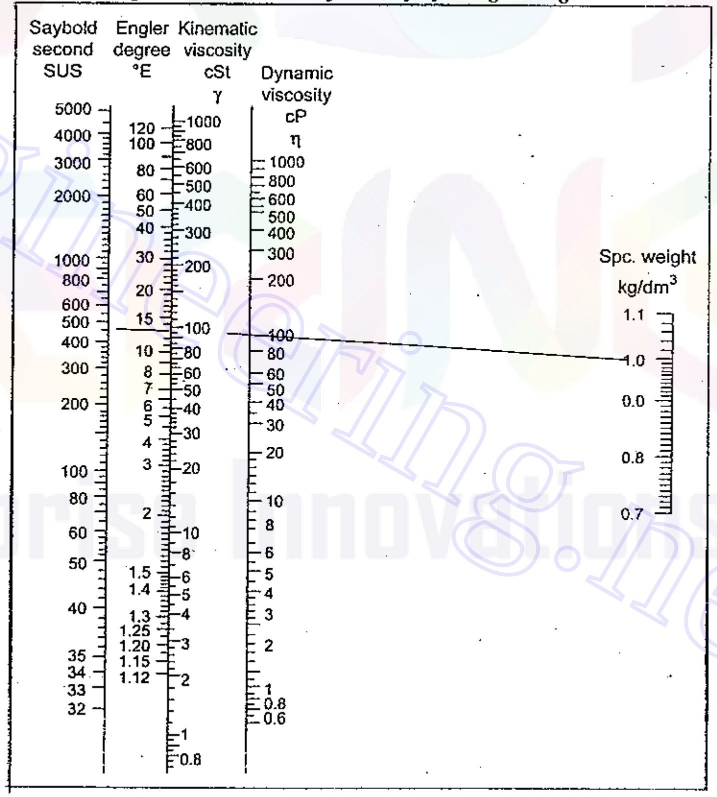


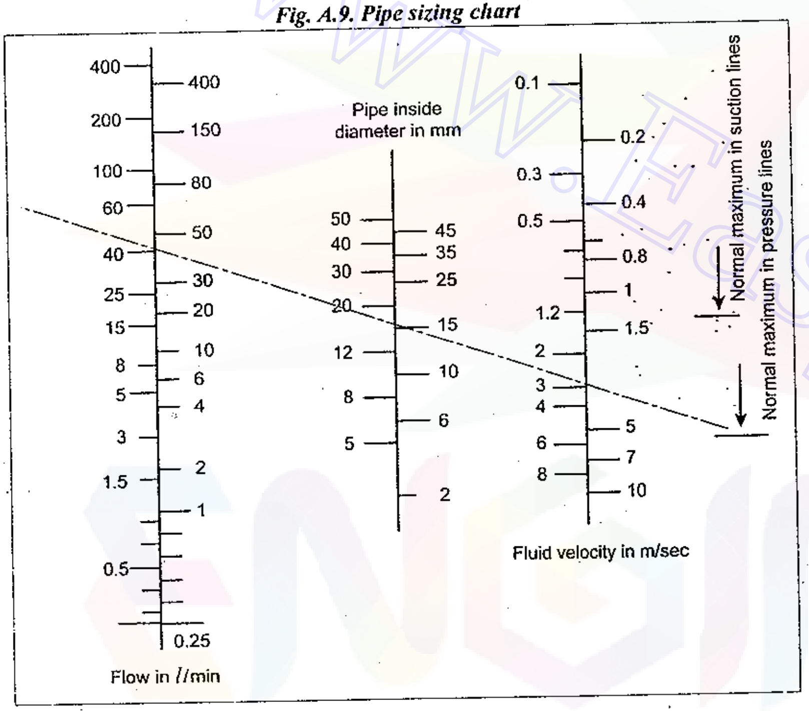
Fig. A.8. Calculation of velocity by using monograms



This type of nomograms is used for the conversion of viscosity units. For instance, if the iematic viscosity of an oil (ν) is 100 cSt and specific weight is 1 kg/dm^3, then its uivalent other viscosity units can be found by joining the points in the scale, as shown in g.A.8. For this case, we get ν = 13°E or 500 SUS.

PIPE SIZING CHART

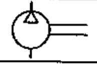
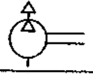
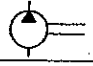
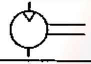
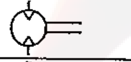
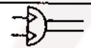
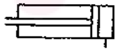
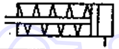
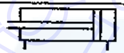
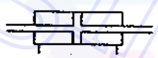
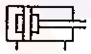
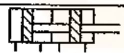
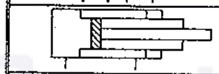
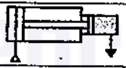
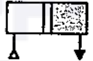
Fig. A.9. Pipe sizing chart

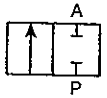
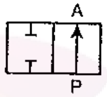
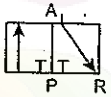
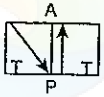
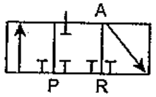
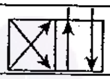
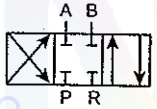
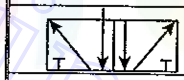
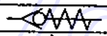
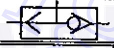
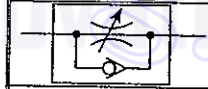
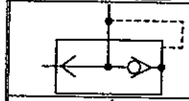
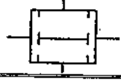


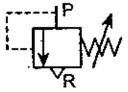
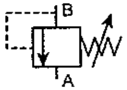
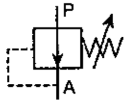
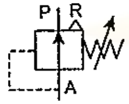
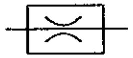
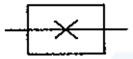
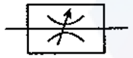
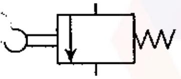
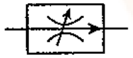
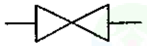
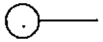
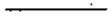
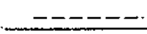
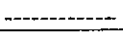
This pipe sizing chart can be used to find the approximate tube bore size required in a luid power circuit. For example, when required flow rate in Lpm and flow velocity in m/sec re known, then by drawing a straight line in the scale we can get the bore size required from he centre scale.

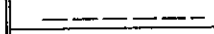
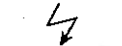
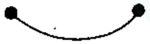
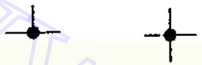
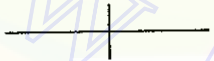
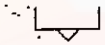
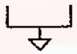
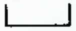
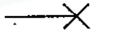
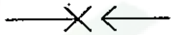
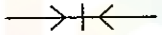
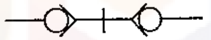
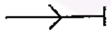
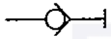
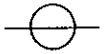
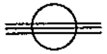
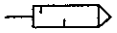
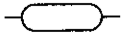
F. FLUID POWER SYMBOLS

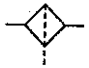
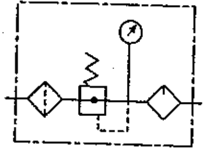
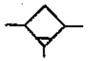
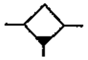
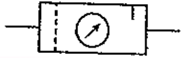
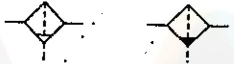
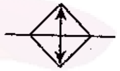
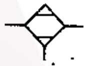
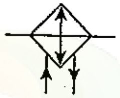
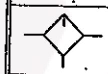
Table A.6. ISO symbols for fluid circuits

Energy conversion	
	Uni-directional air-compressor
	Vacuum pump
	Hydro pump
Air motor	
	Pneumatic motor uni-directional
	Pneumatic motor two-directional
	Oscillating motor
Cylinder	
	Single acting cylinder return by external force
	Single acting cylinder return by spring
	Double acting cylinder
	Double acting cylinder with through rod
	D.A. cylinder with cushioning at both ends
	Tandem cylinder
	Telescoping cylinder
	Pressure intensifier
	Pressure medium changer
Nomenclature Working port - A, B, C Pressure port - P Exhaust port - R, S, T Drain port - L Pilot port - X, Y, Z	Pneumatic - Δ Hydraulic - ▲

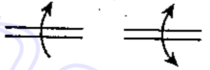
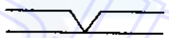
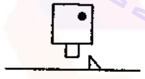
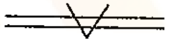
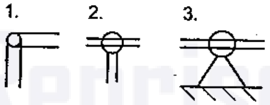
Control valve	
Directional control valve	
	2/2 Directional control valve—normally closed
	2/2 Directional control valve—normally open
	3/2 D.C valve normally closed
	3/2 D.C. valve normally open
	3/3 D.C. valve—zero position all ports closed
	4/2 D.C valve
	4/2 D.C valve—zero position all ports closed
	5/2 D.C valve
Check valve	
	Non-return valve
	Shuttle valve
	Non-return flow control valve
	Quick exhaust valve
	Twin pressure sequence valve

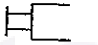
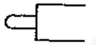
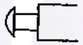
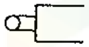
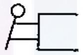
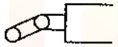
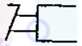
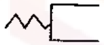
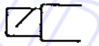
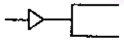
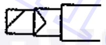
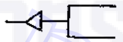
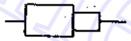
Pressure control valve	
	Pressure relief valve
	Sequence valve
	Pressure regulator
	Pressure regulator with self relieving
Flow valve	
	Flow control general symbol
	Flow control (insignificant influence of viscosity)
	Adjustable flow control
	Flow control valve controlled mechanically with spring
	Pressure compensated flow control valve
Shut-off valve	
	Shut-off valve
Energy transmission	
	Main supply pressure
	Working, return and feed line
	Control line
	Drain line

Energy transmission	
	Assembly line
	Electrical line
	Flexible line
	Line junction
	Crossing line
Exhaust	
	Unthreaded air exhaust port
	Threaded air exhaust port
	Hydraulic tank
Power take off	
	Plugging
	With take off line
Quick release coupling	
	Coupled without check valve
	Coupled with check valve
	Half of quick release-coupling without valve
	Half of quick release coupling with closed valve
Rotary connections	
	One line of flow
	Three lines of flow
	Silencer
	Accumulator

Servicing			
	Filter		Service unit (detailed symbol)
	Water trap manual drain		
	Water trap—automatic draining		Service unit (simple symbol)
	Filter with water trap and drain		Cooler without flow lines
	Desiccator air dry by chemicals		Cooler with flow lines
	Lubricator		

Actuations

Mechanical components	
	One direction of rotation or two respectively of shaft
	Detent
	Locking device
	Over-centre device
	Linkages 1. simple 2. with linkages 3. with fixed fulcrum

Control methods			
Mechanical components		**Mechanical components**	
	General symbol		Plunger
	Push button		Roller
	Lever		Roller-trip
	Pedal		Spring
Electrical control		**Pressure control**	
	Electro-magnet		By applying pressure
	By solenoid and servo valve		By releasing pressure
			By differential pressure

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Glossary
of
Terms

GLOSSARY

Accumulator A fluid pressure storage chamber in which fluid pressure energy may be stored and from which it may be withdrawn.

- **bladder-type** A hydropneumatic accumulator in which the liquid and gas are separated by an expandable bladder or elastic bag.
- **diaphragm-type** A hydropneumatic accumulator in which the liquid and gas are separated by a flexible diaphragm.
- **non-separator-type** An accumulator in which a compressed gas operates directly upon the liquid in the pressure chamber.
- **piston-type** An accumulator in which a compressed gas operates on a piston which applies force to the stored liquid.
- **spring-loaded** An accumulator in which the compression energy is supplied by a spring.
- **weight-loaded** An accumulator in which weights apply force to the stored liquid.

Actuator A device to convert fluid energy into mechanical motion.

- **hydraulic** A device to convert hydraulic energy into mechanical motion.
- **pneumatic** A device to convert pressure energy of air into mechanical motion.

Additive A chemical compound or compounds added to a liquid to change its properties.

Adhesion The attraction between the molecules of a liquid and the molecules of a solid boundary surface in contact with the liquid.

Aftercooler A device to reduce air temperature to convenient levels and to act as a first stage in the removal of moisture prior to entering an air dryer.

Air, compressed Air at any pressure greater than atmospheric.

Air, free Air at normal atmospheric conditions.

Air, standard Standard air is sea-level air having a temperature of 20°C, a pressure of 101 kPa (abs), and a relative humidity of 36%.

Air control valves Devices used to control the pressure, flow rate, and direction of air in pneumatic circuits.

Air dryer A device to remove virtually all moisture by lowering the temperature of the pressurized air to a dew point of 50°F.

Air filter A device to remove contaminants from the air before it reaches pneumatic components.

Air lubricator A device to ensure proper lubrication of internal moving parts of pneumatic components.

Air-to-hydraulic pressure booster A device used for converting shop air into the high hydraulic pressure needed for operating hydraulic cylinders.

Atmosphere The earth surrounded by a blanket of air.

Autogeneous ignition temperature (AIT) The temperature at which ignition occurs spontaneously.

Autoignition temperature (AIT) Nothing but autogeneous ignition temperature (AIT).

Bar A unit of pressure. 1 bar = 10^5 N/m^2

Barometer A device to measure atmospheric pressure.

Bernoullis principle In an ideal, incompressible fluid when the flow is steady and continuous, the sum of potential energy, kinetic energy and pressure energy is constant across all sections of the pipe.

Bleed A controlled take-off of a small amount of fluid from a pressure system.

Boolean algebra It is an 'algebra of logic'. This system formulated logical statements symbolically so that they could be written and proven in a similar manner as used in ordinary algebra.

Boyle's law If the temperature of a given amount of gas is held constant, the volume of the gas will change inversely with the absolute pressure of the gas.

Bourdon gauge One of the most widely used pressure-measuring devices.

Brake power The power obtained from a rotating shaft.

Breather A device which allows air to move in and out of a fluid reservoir to compensate for fluctuating levels.

lk modulus The reciprocal of compressibility. It is a measure of incompressibility.

pass An alternate route which provides passage for a liquid around a component.

pacity coefficient It is the flow rate of water in Lpm that will flow through the valve at a pressure drop of 1 kPa.

ipillarity It is a phenomenon by which a liquid rises into a thin glass tube above or below the general level.

irtridge A component which can be removed and replaced easily without being fully dismantled.

avitation A phenomenon of formation of cavities in a liquid across which the liquid can move with high velocity; producing a hammer effect on any object it strikes. Cavitation generally causes noise and damage to system components.

entipoise A unit of absolute viscosity.

entistroke A unit of kinematic viscosity.

entral processing unit (CPU) It receives input data, executes the stored program, and delivers corresponding output signals to various load control devices.

harles' law If the pressure on a given amount of gas is held constant, the volume of the gas will change in direct proportion to the absolute temperature.

ircuit An arrangement of components and interconnecting pipes.

losed loop A system in which the output is fed back to the input signal.

Cloud point The temperature at which wax or other dissolved solids first precipitate during chilling under specified conditions.

Coanda effect When a stream of air/fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall.

Cohesion It is the intermolecular attraction between molecules of the same liquid.

Compatibility It is the ability of the fluid to be compatible with the system.

Compressibility It is the reduction in volume of a liquid when pressure is applied.

Compressor A machine that compresses air or another type of gas from a low inlet pressure (usually atmospheric) to a higher desired pressure level.

Contact sensing Sensing of objects by physical contact.

Contaminant Deterimental matter in a fluid.

Continuity equation If no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be same.

Control A device used to regulate the functions of a component or system to which it is usually connected; may be integral or remote.

automatic A control actuated in response to a signal from the system; also a control which actuates equipment in a predetermined manner.

electric A control actuated by an electrical device.

fluidic A control system that use logic devices to switch a fluid from one outlet of the device to another outlet.

hydraulic A control actuated by liquid pressure.

liquid-level A device which controls the liquid level, such as a float switch.

mechanical A control actuated by linkages, cams, gears, screws, or other mechanical means.

pneumatic A control actuated by air or other gas pressure.

pump Controls applied to hydraulic pumps to adjust their output or direction of flow.

servo A control actuated by a feed-back system which compares the output with the reference signal and makes corrections to reduce the difference.

Conduction Process by which heat flows from a region of higher temperature to a region of lower temperature within a medium or between different media in direct physical contact.

Convection Transference of heat by moving masses of matter.

Cooler A heat exchanger which removes excessive heat from fluid.

Cracking pressure The pressure at which a valve begins to pass fluid.

Cushion A device inside an actuator which provides controlled deceleration of a load.

Cylinder A linear actuator which converts pressure energy into mechanical force.

double-acting A cylinder which moves in either direction due to fluid flow and pressure.

double-end rod A cylinder with a single piston and with a rod extending from each end.

piston-type A cylinder in which the movable element has a greater cross-sectional area than the piston rod.

plunger-type A cylinder in which the movable element has the same cross-sectional area as the piston rod.

single-acting A cylinder in which the fluid pressure is applied in only one direction.

single-end rod A cylinder with a rod extending from one end.

tandem Two or more cylinders with interconnected piston assemblies.

telescoping A cylinder with nested multiple tubular rod segments which provide a long working stroke in a short retracted envelope.

Darcy's equation Used to calculate the head loss due to friction in pipes for both laminar and turbulent flow.

Density The quantity of matter contained in unit volume of the substance.

mass The mass of the fluid per unit volume.

relative The ratio of mass (or weight) density of a fluid to mass (or weight) density of a standard fluid.

weight The weight of the fluid per unit volume.

DCV Directional control valve.

Demulsibility The property to separate rapidly and completely from moisture and to resist emulsification.

Detent A device which mechanically locks a valve spool in the selected position.

Diaphragm It is a dividing membrane or thin partition.

Differential pressure The net effective result of two different pressures acting on separate areas.

Drain It is the passage that returns fluid from a component under low pressure to the reservoir.

Efficiency The ratio of the output power to the input power.

mechanical Indicates the amount of energy losses that occur for reasons other than leakage.

overall Considers all energy losses.

volumetric Indicates the amount of leakage that takes place within the pump.

Elastomer An elastic, rubber-like material.

Electro-hydraulic A component which converts an electrical signal into a hydraulic signal.

Emulsion An intimate dispersion of one liquid within another.

Energy The ability or capacity to do work.

Film strength The ability of a liquid to maintain a film.

Filter A device that continuously removes suspended solid particles from hydraulic fluid.

Fire point The temperature at which a liquid will burn continuously when ignited by a small flame under carefully specified conditions.

Fire-resistant fluid A fluid difficult to ignite and which shows little tendency to propagate flame.

Flash point The temperature at which the oil surface gives off sufficient vapours to ignite when a flame is passed over the surface.

Flow, laminar A flow situation in which motion occurs as a movement of one layer of fluid upon another.

Flow, turbulent A flow situation in which the liquid particles move in a random manner.

Flow rate The unit volume of a fluid flowing per unit of time.

Flowmeter A device used to measure the flow rate of a fluid.

Fluid A substance which yields to any pressure tending to alter its shape. It includes both liquid and gas.

Fluid conditioners Devices need to make air a more acceptable fluid medium for the pneumatic system as well as operating personnel.

Fluidics It is the technology that utilizes fluid flow phenomena in components and circuits to perform a wide variety of control functions.

Fluidic sensor A device that senses a change in some parameter and as a result causes a related change in another parameter that can be recognized and interpreted.

Fluid power It is the technology that deals with the generation, control and transmission of power using pressurized fluids.

Fluid power system A system that transmits and controls power through use of a pressurized fluid within an enclosed circuit.

Foam An intimate mixture of gas and liquid occupying much more volume than the liquid alone.

Freezing point The temperature at which a fluid changes from liquid phase to solid phase.

FRL unit Filter–Regulator–Lubricator unit.

Friction Resistance to motion due to the viscosity of the fluid.

Gay-Lussac's law If the volume of a given gas is held constant, the pressure exerted by the gas is directly proportional to its absolute temperature.

General gas law $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Head The vertical distance between a point in a system and the surface of the fluid in a reservoir.

Heat exchanger A device which transfers heat from one medium to another.

Hose A flexible conduit for conveying fluid.

Hydraulic balance A condition in which opposing hydraulic forces are equal.

Hydraulic cylinder A device which converts hydraulic energy into linear mechanical motion.

Hydraulic fuse It prevents hydraulic pressure from exceeding on allowable value in order to protect circuit components from damage.

Hydraulic jack It amplifies the hydraulic force in the hydraulic system.

Hydraulic motor A device which converts hydraulic energy into rotary mechanical motion.

Hydraulic power system A means of energy transmission in which a hydraulic fluid is used as an energy-transmitting medium.

Hydropneumatic The combination of hydraulic and pneumatic power in a unit.

Hydrostatic transmission A drive system which transmits power from a rotary input to a remote rotary output by means of fluid under pressure.

Intensifier A device which increases the working pressure over that delivered by a primary source.

Indicator lamp Used to determine which solenoid operator of a DCV is energized.

Isentropic Having the same properties in all directions.

Isothermal Describing a condition of constant temperature.

Ladder diagram A representation of hardware connections between switches, relays, solenoids, *etc.*, which constitute the basic components of an electrical control system.

Level gauge A device for indicating the amount of fluid contained in a reservoir.

Limit switch It opens and closes circuit when it is actuated either at the end of the extension or retraction strokes of hydraulic or pneumatic cylinders.

Line A tube, pipe, or hose that is used as a conductor of fluid.

Lubricity Ability of a liquid to impart low friction under boundary conditions.

Manifold A fluid passage which connects with a number of inputs or outputs at the same time.

Manual override A means of manually operating an automatic control.

Meter To regulate the flow of fluid in a circuit.

Meter-in To regulate the flow of fluid into an actuator in a pressure line.

Meter-out To regulate the flow of fluid out of an actuator in the tank or drain line.

Moody diagram Used to determine the valve of the friction factor for use in Darcy's equation.

Motor A device for converting fluid energy into mechanical motion.

fixed-displacement A rotary motor in which the displacement per revolution is fixed.

oscillatory A rotary actuator giving an angular movement of less than 360°, sometimes referred to as a rotary hydraulic actuator.

rotary A motor producing continuous rotary motion.

variable-displacement A rotary motor in which the displacement per revolution is adjustable.

Moving part logic (MPL) device MPL devices are miniature valve-type devices, which perform switching operations in fluid logic systems by the action of internal moving parts.

MPL Moving part logic.

Muffler Used to control the noise caused by a rapidly exhausting airstream flowing into the atmosphere.

Neutralization number A measure of the relative acidity or alkalinity of a hydraulic fluid and is specified by a pH factor.

Open loop circuit A circuit in which there is no automatic feedback to the control signal.

O-ring An endless packing ring of circular cross section normally mounted in a groove in such a manner that the effectiveness of sealing increases with the pressure.

Oxidation A chemical reaction of oxygen with a liquid, resulting in the formation of oxidation products, which can cause changes in properties.

Packing Any material or device used to prevent leakage. Packings, seals, and gaskets are often considered synonymous.

Pascal's law It states that pressure applied to a confined fluid is transmitted, undiminished in all directions.

Perfect gas laws Include Boyle's law, Charles' law, Gay-Lussac's law, and the general gas law.

Pilot control A method of operating valves and other devices by means of a small independent pressure signal.

Pilot line A tube or hose which conducts control fluid.

Piping All pipe, tubing, hose, and fittings.

Piston ring A sealing ring which normally fits in grooves in the piston head.

PLC Programmable logic controllers.

Pneumatic cylinder A device which converts pressure energy of the compressed air into linear mechanical motion.

Pneumatic indicator Nothing but pressure gauge.

Pneumatic motor A device which converts pressure energy of the compressed air into rotary mechanical motion.

Pneumatic silencer Also called muffler, used to control the noise caused by a rapidly exhausting airstream flowing into the atmosphere.

Poise The standard unit of absolute viscosity.

Poppet A cylindrical valve having a cone-shaped seat.

Port The inlet or outlet connection in a valve, pump or actuator.

Positive displacement A fixed output per revolution or stroke, irrespective of pressure variations.

Pour point The lowest temperature at which a liquid will flow under specific conditions.

Power The rate of doing work.

Power pack Describes a unit which usually includes a fluid reservoir, electric motor, pump, and essential control valves.

pre-charge The residual pressure in a hydraulic accumulator before the introduction of oil.

Pressure Force per unit area.

absolute The sum of atmospheric and gauge pressures.

atmospheric Pressure exerted by the atmosphere at any specific location.

operating The pressure at which a system is operated.

static The pressure that exists if there is no motion in the liquid.

suction The pressure of the liquid at the inlet of a pump.

Pressure booster Also known as pressure intensifier, used to increase the pressure in a hydraulic system to a valve above the pump discharge pressure.

Pressure-compensated Describes a pump or control valve whose output is automatically regulated in response to fluctuations in system pressure.

Pressure drop The amount of pressure difference in a circuit.

Pressure gauge A device to measure gauge pressure.

Pressure intensifier See pressure booster.

ressure line The pipe or manifold which carries fluid under pressure from the pump to the rest of the circuit.

ressure loss The fall in pressure due to hydraulic friction in a component or circuit.

ressure switch An instrument that automatically senses a change in pressure and opens or closes an electrical switching element when a predetermined pressure level is reached.

Programmable logic controller (PLC) A user friendly electronic computer designed to perform logic functions for controlling the operation of industrial equipment and processes.

Programmer/Monitor (PM) This unit allows the user to enter the desired program into the RAM memory of the CPU.

Pump A device which converts mechanical energy into fluid energy.

axial piston (constant volume) A pump with a fixed volumetric output and with multiple pistons having their axis parallel to the drive shaft.

axial piston (variable volume) An axial piston pump with an adjustable controlled volumetric output.

centrifugal A pump having an impeller rotating in a housing with liquid carried around the periphery of the housing and discharged by means of centrifugal force.

gear A pump having two or more intermeshing gears or lobed members enclosed in a suitably shaped housing.

radial piston (constant volume) A pump with a fixed volumetric output having multiple pistons disposed radially.

radial piston (variable volume) A radial piston pump with an adjustable volumetric output.

reciprocating A pump having reciprocating pistons to pressurize fluid.

screw A pump having one or more screws rotating in a housing.

two-stage A pump with two separate pumping elements connected in a series.

vane (constant volume) A pump having a fixed volumetric output with multiple vanes within a supporting rotor, encased in a cam ring.

vane (variable volume) A vane pump having suitable means of changing the volumetric output.

Pump ripple Small variations of fluid flow that takes place.

Pump slip It is the leakage that occurs between the discharge and suction sides of a pump through the pump clearances.

Receiver A container in which gas (*i.e.*, air) is stored under pressure as a supply source for pneumatic power.

Radiation The process by which heat flows from a high-temperature body to a body at a lower temperature when the bodies are separated in space, even when a vacuum exists between them.

Regeneration An automatic control system which allows a cylinder to advance quickly at low pressure, then apply full pressure at a lower speed when a higher thrust is required.

Relative roughness The ratio between the pipe inside surface roughness and the pipe inside diameter.

Relay An electrically actuated switch.

Reservoir The storage tank for hydraulic fluid.

Return line The pipe or manifold which carries low pressure fluid back to the reservoir.

Reynold's number A dimensionless number used in considerations of fluid flow and given by the formula : $\text{Re} = \dfrac{\text{(velocity) (Pipe diameter)}}{\text{Kinematic viscosity}}$

Rotameter A flow measuring device.

Rotary actuator A device to convert fluid energy into rotary mechanical motion.

Saybolt Universal Second (SUS)) An official unit to measure the viscosity of the oil.

Saybolt viscometer A device to measure the viscosity of the oil.

SCFM Standard cubic feet per minute.

Seal A material or device designed to prevent leakage between parts, moving or static.

Sequence The order in which various operations take place in a fluid power system.

Servo A device used to convert a small movement into a greater movement of force.

Shock absorber A device that brings a moving load to a gentle rest through the use of metered hydraulic fluid.

Silencer See muffler.

Solenoid An electromagnet consisting of a wire-wound coil with a moving plunger which moves when the electric current is switched on.

Specific gravity The ratio of the weight density of the fluid to the weight density of water.

Specific weight Nothing but weight density.

SRT flip-flop SET-RESET-TRIGGER flip-flop.

Stability Resistance to permanent changes in properties under normal storage and use conditions.

hydrolytic Resistance to permanent change in properties caused by chemical reaction with water.

oxidation Resistance to permanent changes in properties caused by chemical reaction with oxygen.

thermal Resistance to permanent changes in properties caused solely by heat.

Stoke The standard unit of kinematic viscosity. It is expressed in cm^2/s.

Strainer A coarse filter.

Suction line The pipe or manifold which connects the pump inlet port to the fluid reservoir.

Surge A temporary uncontrolled use in pressure or flow.

Swashplate An inclined disk or plate in an axial piston pump or motor which causes the pistons to reciprocate.

Tank The fluid reservoir.

Thermostat A device for controlling temperature.

Throttle A restriction to normal flow.

Timer Time delay device used to control the time duration of a working cycle.

Torque Force applied through a rotary path of motion.

Tree-branching chart A chart used to amplify the troubleshooting process.

Troubleshooting An organised and systematic study of the problem and a logical approach to the difficulty faced in the system.

Two-handed safety circuit Designed to protect an operator from injury.

Unload To release the pressure from part of the system.

Valve A device for controlling flow rate, direction of flow, or pressure of a liquid.

check A valve which permits flow of fluid in one direction only and self closes to prevent any flow in the opposite direction.

closed center A valve which in the center position has all ports closed.

directional A valve whose primary function is to direct or prevent flow through selected passages.

flow control A valve whose primary function is to control flow rate.

flow dividing A valve which divides the flow from a single source into two or more branches.

four-way A valve having four controlled working passages, usually ending in four external ports.

gate A valve with a gate which is raised or lowered to close or open the flow passage.

globe A valve with a plug, ball, or disc, is pulled away from or lowered into a corresponding seat to open or close the flow passage.

needle The tapered needle permits gradual opening or closing of the passage.

non-return A valve which normally allows flow in one direction only.

open center A valve which in the center position connects all ports.

pilot A valve applied to operate another valve or control.

pilot-operated A valve in which operating ports are actuated by pilot fluid.

poppet-type A valve construction which closes off flow by a poppet seating against a suitable seating material. The poppet may be a ball, a cone, or a flat disk.

pressure reducing A valve which maintains a reduced pressure at its outlet regardless of the higher inlet pressure.

quick exhaust A fast exhaust valve used to vent cylinders quickly.

ief A valve which opens when a set pressure is reached to prevent further rise of pressure in a system or to keep the pressure constant.

sequence A valve which automatically allows two functions to take place, one after another in strict sequence.

sero A valve which automatically regulates its output in accordance with a feedback monitoring signal.

ittle A connective valve which selects one of two or more circuits because flow or pressure changes between the circuits.

spool-type A valve construction using a spool consisting of undercuts or recesses on a cylinder of metal.

three-position A valve having three positions to give three selections of flow conditions.

three-way A directional control valve having three distinctive external working connections.

two-position A valve having two positions to give two selections of flow conditions.

two-way A DCV having two distinctive external working connections.

unloading A valve which allows pressure to build up to an adjustable setting, then bypasses the flow as long as the preset pressure is maintained on the pilot port by a remote source.

time delay A valve in which the change of flow occurs only after a desired time intervals has elapsed.

Vapour pressure The pressure exerted by a material under consideration at a specified temperature.

Vent A small valve or opening to allow the removal of air.

Viscometer A device for measuring viscosity.

Viscosity A measure of the internal friction or the resistance of a fluid to flow.

kinematic The ratio of absolute viscosity to the density of a fluid.

Viscosity index (V.I) A measure of the viscosity-temperature characteristics of a fluid as referred to that of other fluids.

Volatility The property of a fluid describing the degree to which it will vapourize under given conditions of temperature and pressure.

Wiper ring A seal designed to prevent foreign abrasive or corrosive materials from entering a cylinder.

□□

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"The object of education is to prepare the young to educate themselves throughout their lives."

– Robert Maynard Hutchins

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UNIT CONVERSION FACTORS

LENGTH

1 metre (m) = 3.281 foot (ft) = 1000 millimetre (mm) = 100 centimetre (cm)
1 inch (in) = 25.4 mm = 2.54 cm
1 yard (yd) = 0.9144 m

AREA

1 in^2 = 6.452 cm^2 ; 1 ft^2 = 0.0929 m^2

VOLUME

1 in^3 = 16.387 cm^3 ; 1 ft^3 = 28.317 litres (L)
1 gallon (gal) = 3.785 L = 231 in^3 = 0.135 ft^3 ; 1000 L = 1 m^3

MASS

1 kilogram (kg) = 2.2046 pound (lb) = 1000 gram (gm)
1 lb = 0.4536 kg ; 1 ton = 1016 kg ; 1 slug = 14.59 kg

FORCE

1 newton (N) = 0.2248 pound force (lbf) = 0.1019 kilogram force (kgf)
1 lbf = 4.448 N = 0.4534 kgf ; 1 kgf = 9.81 N = 2.205 lbf
1 N = 105 dynes (dyn) ; 1 N = 1 kg m s^{-2}

PRESSURE

1 bar = 10^5 pascal (Pa) = 14.5 pound force per square inch (psi) = 750 mm Hg
= 1.0197 kgf.cm^{-2}
1 atmosphere (atm) = 1.013 bar = 14.7 psi = 1.033 kgf.cm^{-2}
1 psi = 6895 Pa ; 1 Pa = 1 N.m^{-2}

VELOCITY

1 ft/s = 0.3048 m/s ; 1 rpm = 0.1047 rad/s

WORK (ENERGY)

1 joule (J) = 1 N.m = 1 kg.m^2.s^{-2} = 10^7 ergs = 0.7376 ft.lbf
1 J = 2.788 × 10^{-7} kilowatt hour (kWh) = 0.2388 calories
= 9.487 × 10^{-4} British thermal units (Btu)

POWER

1 horse power (hp) = 745.7 W = 550 ft.lb/s = 42.4 Btu/min

FLOW RATE

1 ft^3/s = 0.0284 m^3/s = 448 grams per minute (gpm) ;
1 gpm = 0.0632 litres per second (Lps)

VISCOSITY

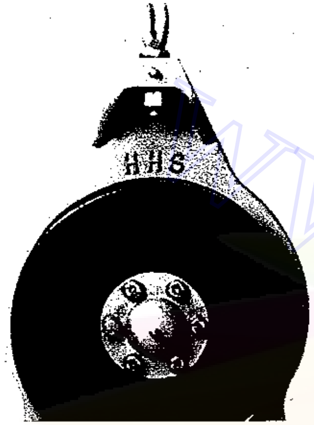
Viscosity (absolute) : 1 N.s/m^2 = 10 poise ; 1 poise = 1 dyn.s/cm^2
1 lb.s/ft^2 = 47.88 Pa.s
Viscosity (kinematic) : 1 m^2/s = 10,000 strokes ; 1 stroke = 1 cm^2/s
1 ft^2/s = 0.0929 m^2/s

TEMPERATURE

T (°C) = (°F–32) × 0.556 ; T(K) = T(°C) + 273
T (°F) = (°C × 1.8) + 32

APPLIED HYDRAULICS & PNEUMATICS

V. Jayakumar



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